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

Hydrogen Contamination Detector Workshop

Workshop held June 12, 2014

SAE International, Troy, Michigan

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SAE International, Troy, Michigan

Sponsored by:

U.S. Department of Energy (DOE)

Energy Efficiency and Renewable Energy (EERE)

Fuel Cell Technologies Office (FCTO)

Hosted by:

SAE International

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Executive Summary

On June 12, 2014, the Hydrogen Contamination Detector (HCD) Workshop was held at the Society for Automotive Engineers (SAE) Headquarter Building in Troy, MI to gather individual input on HCD requirements from key stakeholders. Feedback was sought to understand suitable technologies and research and development (R&D) gaps and needs for use at hydrogen refueling stations (HRS). This input helped identify technical and performance requirements for HCDs, current state-of-the-art detection technologies for the near-term, and the R&D advancements needed for low-cost, accurate, and robust detectors for the long-term. The workshop drew on experts from original equipment manufacturers (OEMs), industrial gas companies, oil and gas companies, fuel cell manufacturers, national labs, regulatory bodies, energy research institutions, and developers of detection technologies to provide individual input and discussion, organized into three broad topics over the course of one day:

1. Technical and performance requirements for detection of fuel quality at the station
2. Near-term solutions to meet deployment requirements
3. Long-term R&D areas to address technical gaps

Industry experts expressed strong support for the deployment of an HCD device to address near-term challenges. However, a long-term solution may differ from the technologies or contaminant detection measures which are currently available or likely to be deployed in the next 2 to 3 years.

The workshop participants identified key technical and performance solutions addressing the most pressing challenges, including:

- Develop sampling requirements based on real-world conditions.
- Establish a panel to identify suitable detector locations and sample.
- Accelerate development and deployment timelines for HCDs.
- Support deployment of existing technologies.
- Explore alternate locations for locating HCDs (e.g., upstream of compression, storage, and dispensing (CSD) hardware to minimize false positives).

Proposed solutions and strategies identified to address near-term deployment requirements include the following:

- Determine and delineate fueling station and fuel supplier responsibilities regarding the provision of contaminant-free fuel; the location and detection limit of HCDs; and frequency of sample analyses.
- Investigate pro-active solutions and alternative methods of fuel quality validation that would preclude the need for an HCD.
- Deploy low-cost HCDs (e.g., capital cost of less than 1% of station capital expenditures) for CSD systems.
- OEM and station provider agreement on quality assurance (QA) and quality control (QC) policies for all HRS (i.e., quarterly maintenance requirements for HRS).
- Develop a fuel quality database to track station performance for all existing stations.

The discussions on long-term R&D areas and technical gaps provided valuable information to guide future efforts:

- Develop a HCD industry standards and requirements report to guide future R&D, including robustness and reliability testing and sampling protocols.
- Integrate enrichment devices into HCDs to enable detection of the low concentrations specified in SAE J2719 limits.
- Assign a panel to evaluate HCD technology gaps and recommend a strategy to address stakeholder needs.

The stakeholder community represented at this workshop agreed that the HCD is necessary and should serve as a critical component in a contamination detection system or framework. This might include alternative methods of detection or more rigorous QC and QA measures both upstream and downstream in the hydrogen fuel supply chain. Overall, this workshop provided critical input on the near-term and long-term priorities regarding the definition of the functionality, technical and performance parameters, and the roles that key stakeholders must play to enable deployment of HCDs that can satisfy industry needs. The input received by key stakeholders is summarized in this report.

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Workshop Proceedings and Organization

The workshop opened with an introductory presentation by Will James from the U.S. Department of Energy (DOE) on the Fuel Cell Technologies Office (FCTO). He outlined R&D activities and identified needs with respect to HCDs. This led into presentations on the OEM perspective from Timothy McGuire of Mercedes-Benz R&D NA, Inc. and Mike Steele, an independent consultant, on the current fuel quality challenges facing fuel cell electric vehicle (FCEV) manufacturers. Herie Soto from Shell presented the station operators' perspective on current hydrogen fuel quality challenges.

Next were presentations on existing and potential contaminant detection devices and associated R&D needs, from a panel of experts. A question and answer session was held following the presentations. William Buttner from the National Renewable Energy Laboratory (NREL) presented deployment requirements for HCDs. This was followed by a presentation on specialized applications by Andrew Kaldor from Power+Energy. Lastly, an overview of R&D sensing techniques was presented by Rangachary Mukundan of Los Alamos National Laboratory (LANL) and concluded with a presentation by JP Hsu of Smart Chemistry on approved laboratory methods for hydrogen contaminant detection.

The balance of the workshop consisted of a panel discussion, a moderated session on technical and performance requirements, and two concurrent breakout sessions (near-term solutions and long-term R&D). For the moderated session, all workshop attendees participated in a discourse with panel experts (William Buttner/NREL; Andrew Kaldor/Power+Energy; Rangachary Mukundan/LANL; and JP Hsu/Smart Chemistry) on the topics of detector performance requirements; refueling system integration requirements; and hydrogen contaminant detection devices that currently exist. The workshop participants then divided into two groups–each with roughly half of the participants–for participation in the concurrent breakout sessions.

Each breakout session started with brainstorming exercises with the participants identifying challenges on notecards. These notecards were categorized and displayed for participants to observe. Following this exercise, each attendee identified ideas they perceived to be of the highest priority. This led to a similar brainstorming exercise focused on identifying solutions and activities to address the prioritized challenges.

Introduction

The workshop began with a welcome and introduction led by Will James of the DOE. He provided an overview of the FCTO mission, key goals and targets for automotive fuel cell applications, and an overview of the office-level strategy that is employed to achieve these targets for automotive and other fuel cell applications.

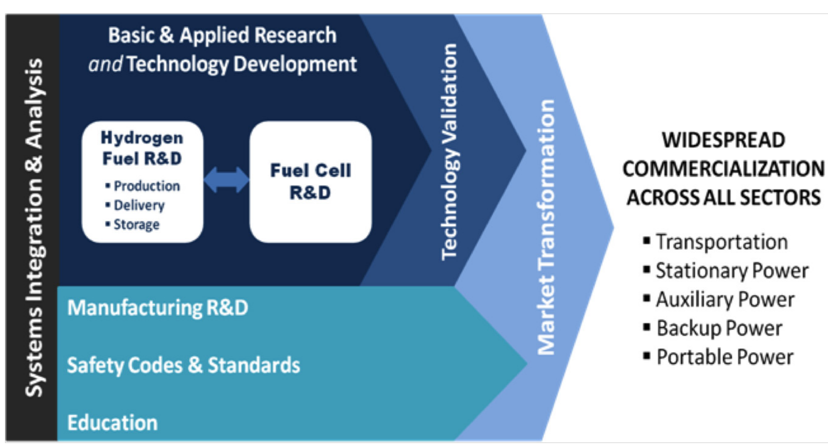

Figure 1. Overview of FCTO Organization and Strategy

Will James also described the research, development, and demonstration (RD&D) activities that are currently being funded by the DOE to reduce costs and improve the reliability and performance of fuel cells. In addition, he emphasized the early market challenges that must be overcome to achieve widespread commercialization of FCEVs. Specifically, these include the need for station cost reduction, identification of strategic station locations, attraction of investment and finance for deploying stations and emphasis on market support and acceleration. A public-private partnership (H2USA) has been established to address these challenges alongside the R&D and market transformation efforts of FCTO. A new project, the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) has been initiated to address technical barriers to infrastructure deployment. This is a collaborative effort with industry and will leverage existing and emerging capabilities at national laboratories. It is focused on accelerating cost reductions and station deployment timelines and improving reliability of stations.

Lastly, Will James provided an overview of the current status of hydrogen fueling infrastructure in the U.S. Currently there are 10 stations open and operating in California (see Table 1 below), and 48 stations in development as a result of a $46.6 million investment by the California Energy Commission (CEC) for hydrogen refueling stations. The stations currently under construction include both gaseous and liquid hydrogen stations with a capacity ranging from 25 kilograms (kg) per day to 200 kg per day. Several states, including Connecticut, Hawaii, Ohio, New York, and South Carolina, have major hydrogen and fuel cell programs underway. In addition, 8 states have recently signed a Memorandum of Understanding (MOU) to deploy 3.3 million zero-emission vehicles (ZEVs) on U.S. roadways by 2025. The need for HCDs to be deployed at HRS is important both in the near-term and long-term to ensure delivery of high-quality hydrogen that will enable the fuel cell to maintain high levels of performance and reliability for FCEV drivers.

Table 1. Existing Station Type, Hydrogen Source, and Capacity of Current Commercial Stations in California

Station	Type	Source	Capacity
Burbank	Gaseous	SMR	108 kg/day
Emmeryville/AC Transit	Gaseous & Liquid	Electrolyzer & Liquid truck	60 kg/day
Fountain Valley	Gaseous	SOFC (biogas conversion)	100 kg/day
Harbor City	Gaseous	Tube trailer	100 kg/day
UC Irvine	Liquid	Liquid truck	25 kg/day
New Port Beach	Gaseous	SMR	108 kg/day
Thousand Palms	Gaseous	SMR	~200 kg/day
Torrance	Gaseous	Pipeline	50 kg/day
West LA	Gaseous	Electrolyzer	32 kg/day
CSU-LA	Gaseous	Electrolyzer	60 kg/day

Current Fuel Quality Challenges

Several presentations were given to provide further insight into the perspectives, challenges, and needs as identified by key groups of stakeholders.

First, an overview of fuel quality challenges was provided by automotive OEMs followed by a presentation from a station operator's perspective.

Automotive OEMs' Perspective

Timothy McGuire of Mercedes-Benz R&D NA, Inc. provided an OEM perspective on fuel quality challenges. He emphasized that cars are being manufactured and released based on the specifications of the SAE J2719 – Hydrogen Fuel Quality for Fuel Cell Vehicles. There is a need to ensure that the quality of delivered commercial hydrogen is compliant with SAE J2719 and future revisions.

There is a need to build knowledge and experience with monitoring contamination and its effects in the field. Increased sales of hydrogen from businesses, including OEMs, to consumers will help build confidence that the quality of delivered hydrogen fuel adheres to J2719. Methods and technology solutions to provide such QC and QA will also help build trust between OEMs and the fuel providers.

Mike Steele, Chair of the SAE Fuel Cell Standards Committee, discussed SAE Technical Information Report (TIR) J2719-1. This report is being developed to reduce testing for hydrogen impurities at HRS to ensure compliance with J2719. The TIR was intended for use by both industry and regulators for monitoring of filling station performance. By focusing on impurities that are specific to a particular type of fueling station, the number of contaminants which are targeted by testing measures can be reduced. This can reduce the contaminants to be tested for, hence reducing the cost to the station operator. Table 2 (below) shows the contaminants, their regulated levels as given in SAE J2719, and the relevant American Society for Testing and Materials (ASTM) method developed to measure it.

Table 2. Hydrogen Fuel Quality Specification[1]

Constituent	Chemical Formula	Limits	Laboratory Test Methods to Consider and Under Development	Minimum Analytical Detection Limit
Hydrogen fuel index	H_2	>99.97%		
Total allowable non-hydrogen, non-helium, non-particulate constituent		100 µmol/mol		
Acceptable limit of each individual constituent				
Water	H_2O	5 µmol/mol	ASTM D7653-10, ASTM D7649-10	0.12 µmol/mol
Total hydrocarbons (C_1 basis)		2 µmol/mol	ASTM D7675-11	0.1 µmol/mol
Oxygen	O_2	5 µmol/mol	ASTM D7649-10	1 µmol/mol
Helium	He	300 µmol/mol	ASTM D1945-03	100 µmol/mol
Nitrogen, Argon	N_2, Ar	100 µmol/mol	ASTM D7649-10	5 µmol/mol
Carbon dioxide	CO_2	2 µmol/mol	ASTM D7649-10, ASTM D7653-10	0.1 µmol/mol
Carbon monoxide	CO	0.2 µmol/mol	ASTM D7653-10	0.01 µmol/mol
Total sulfur		0.004 µmol/mol	ASTM D7652-11	0.00002 µmol/mol

[1] Fuel Cell Technologies Office Multi-Year Research, Development and Demonstration (MYRD&D) Plan. http://energy.gov/eere/fuelcells/fuel-cell-technologies-office-multi-year-research-development-and-demonstration-plan

Formaldehyde	HCHO	0.01 µmol/mol	ASTM D7653-10	0.01 µmol/mol
Formic acid	HCOOH	0.2 µmol/mol	ASTM D7550-09, ASTM D7653-10	0.02 µmol/mol
Ammonia	NH_3	0.1 µmol/mol	ASTM D7653-10	0.02 µmol/mol
Total halogenates		0.05 µmol/mol	ASTM WK23815, WK34574	0.01 µmol/mol
Particulate Concentration		1 mg/kg	ASTM D7650-10, ASTM D7651-10	0.005 mg/kg

Station Operators' Perspective

Herie Soto from Shell presented a discussion on fuel quality challenges from a station operator's perspective. Shell operates 15 stations in the U.S. and Europe and performs annual external lab analyses on samples collected from each station following purging cycles conducted during maintenance and when major equipment that can affect the fuel quality is replaced. The recent failure of a membrane in a fuel purifier resulted in dispensed fuel that did not comply with J2719 specifications. Shell is now developing lessons learned and investigating multiple scenarios for diagnosing and preventing similar failures in the future.

Herie Soto noted that conventional gas analyzers that are currently commercially available are not cost-effective nor sufficient for detecting all contaminants at all required levels. These devices are limited to measuring only one or a few contaminants; existing technologies may be suitable for laboratory use but are not proven to be "field-ready" for testing for J2719 compliance. Even with these shortcomings, some technologies may be deployed at HRS.

Panel Discussion

Following the presentations and discussion surrounding current hydrogen fuel quality challenges, overviews of key topics for consideration were provided to further contextualize the subsequent panel discussion and breakout sessions. This portion of the workshop focused on detection devices that are either currently or could soon be commercially available, as well as the industry- and lab-identified R&D needs for both the near- and long-term.

Presentations were given on the following topic areas: HCD deployment requirements; specialized applications for existing and potential contamination detectors; conceptual R&D focused on contaminant sensing techniques; and laboratory applications and findings from HCD analyses. These overviews helped structure the brainstorming activities in the afternoon breakout sessions. These sessions focused on near-term solutions to meeting deployment requirements and long-term R&D areas to address technical gaps.

Deployment Requirements

William Buttner discussed HCD deployment requirements. The presentation covered SAE J2719 requirements, applications, sensor performance parameters, critical metrics, and measurement strategies. He addressed the benefits and potential drawbacks of centralized vs. on-site detection, as well as discreet vs. real-time detection. The sensor performance parameters and critical metrics were discussed in three categories: (1) metrological parameters, (2) deployment parameters, and (3) operational parameters.[2] He also described prescriptive and performance measurement strategies, while also acknowledging the unique challenges of certain sensor technologies. He concluded by noting that limits of short-term fuel exposure to contaminants and limits in detection and/or interface design are key gaps in HCD deployment requirements.

Figure 2. Hydrogen Sensor

[2] Summary and Findings from the NREL/DOE Hydrogen Sensor Workshop. http://www.nrel.gov/docs/fy12osti/55645.pdf

Specialized Applications

Andrew Kaldor from Power+Energy provided an overview of current commercial applications for contamination detectors. He emphasized that current technologies do exist and are deployed in the field, mostly at distribution sites. Power+Energy has developed a novel technology platform for processing hydrogen samples for contamination analysis based on micro-channel technology. A commercially available option is Power+Energy's Hydrogen Elimination Mass Spectrometer (HEMS) analyzer. By concentrating impurities in the hydrogen fuel, the device allows for lower-cost analysis and an effective higher sensitivity to contaminants. This device and similar technologies can help ensure the fuel delivered at the point of sale is J2719-compliant. One suggested strategy was to verify that the total impurity level was less than 1 part per billion (ppb) thereby precluding the need to detect individual impurities. He further noted that opportunities exist to reduce the cost of detection by measuring the total contaminant level – rather than identifying specific contaminants – to signal the user only if it exceeds a pre-determined threshold.

R&D Sensing Techniques

Rangachary Mukundan of Los Alamos National Laboratory spoke about R&D sensing techniques. The overarching concept discussed involved using a device similar to a fuel cell to measure impurities in the fuel stream. Noted advantages of this type of device included its sensitivity to impurities, reasonable cost, and compatibility with impurity concentration systems and fuel stations. Disadvantages included response time; distinguishing long-term exposure to compliant levels of contamination vs. short-term exposure to out-of-compliant levels; and difficulties in quantitatively certifying impurity concentration. Engineering hurdles need to be addressed in order for this concept to transition to a practical device.

Laboratory Applications

JP Hsu of Smart Chemistry delivered a presentation on laboratory methods for contamination detector devices and the typical contaminants found in hydrogen fuel dispensed from a fueling nozzle. He noted that particulates are the most common impurity found in hydrogen fuel, citing roughly 108 particulate samplings in which 96% of hydrogen fuel contained particulates. Most methods have a detection limit of 1 milligram (mg) per kg and JP Hsu emphasized that at a concentration of over 1.2 grams (g) per kg of hydrogen the sample container severely restricted hydrogen flow at 1,000 pounds per square inch (psi) during hydrogen gaseous sampling.

Most hydrogen samples collected by Smart Chemistry contained trace amounts of sulfur. However, high sulfur levels were also occasionally found in hydrogen samples, especially following the installation of new stainless steel tubing. Carbon monoxide (CO) and methane (CH_4) were also present in trace amounts in all of the hydrogen samples, with occasional detection of high-level CO. Nitrogen (N_2) contamination was also typically found in new hydrogen fueling stations. Helium (He) was typically found in hydrogen produced via steam-methane reforming (SMR). Overall, CO_2, O_2, H_2O, argon (Ar), hydrocarbons (i.e., ethanol, isopropanol, etc.), and organic halides (i.e., high-molecular weight Freon, etc.) were frequently found in hydrogen fuel. JP Hsu specified that given these findings, all contaminants that were mentioned above should be monitored frequently in hydrogen fuel, although it was noted that while trace contaminants were detected, for the most part the gas analyses demonstrated that the hydrogen was compliant to J2719 requirements.

Detection of Fuel Quality at the Station

This group session was moderated by Jay Keller, a consultant to FCTO's Safety, Codes and Standards program. The first discussion focused on identifying internal and external challenges to achieving deployment of HCD technologies as they relate to deployment requirements. The second discussion focused on related activities and solutions for deployment of HCD technologies as they relate to requirements that will help resolve the top issues identified in the first exercise.

Technical and Performance Requirements

Questions from a previously released Request for Information (RFI) (see appendix D) on HCD technical and performance requirements were presented as a means of focusing the brainstorming exercise to extract targeted feedback from the workshop attendees. All workshop attendees participated in this activity. The RFI guidance questions that were most relevant to the discussion of technical and performance requirements are listed below:

HCD Requirements

- What aspects of HCD mechanical and electrical interfaces should be standardized? Should connection standards be developed so detectors can be upgraded or replaced easily?
- What is the maximum allowable cost for an HCD solution to be economical?
- Where do HCDs need to be positioned with respect to station components?
- For each of the following questions, please be sure to specify the position of the proposed device (for potential solutions including multiple detector types in various positions).
    - Specify the contaminants that should be detected. What is the source of the contaminant? How severe is the impact on the fuel cell?
    - For each contaminant, what is the minimum sensitivity a device would need to have in order to provide a useful response to the contaminant (for near-term deployment)?
    - For each contaminant, what should the target sensitivity of the device be for long-term R&D?
    - What devices can be used to detect each contaminant? Which is best and why?
- What would the detection device cost? How often would they need to be re-calibrated or replaced? What is the response time?

Each participant had the opportunity to identify their top ideas for internal and external challenges to meeting the DOE objective, then shared them one idea at a time, until all ideas were exhausted. The challenges identified were the result of individual viewpoints expressed by the participants. To recognize the highest priority challenges, each participant was asked to identify the challenges they perceived as important.

During the group session, the attendees each identified the challenges they perceived as important regarding the definition of and compliance with technical and performance requirements by indicating each of their top five choices. In the remainder of this session, attendees brainstormed solutions to facilitate the development of and adherence to technical and performance criteria. Proposed challenges and solutions were grouped into four categories: (1) system specifications, (2) quality control (QC), (3) programmatic timelines, and (4) cost of ownership.

Table 3 below presents a compilation of the results of the brainstorming sessions, including a description of the ideas and the number of attendees identifying potential challenges.

Table 3. Priority Technical and Performance Requirements

Challenges to Defining Technical and Performance Requirements		Number of attendees that identified challenge as important
System Specifications	Need for increased frequency of analysis as a function of station location.	6
	Determination of sensitivity levels and identification of gases to be detected.	6
	Need to identify the purpose of the fuel quality analysis (i.e., process control, quality assurance, etc.).	4
	Distinction between gradual increases in contaminant levels and sudden, sharp rises in concentration and related detector technologies and frequencies of sampling.	3
	Feedback mechanisms needed to halt fueling capability to prevent a foray of contaminants.	3
	Lack of high-pressure filters or a dual filter system for maintenance.	2
	Need for a detector that can be deployed at different parts of the HRS.	2
	Absence of system cleanliness process and related specifications.	2
	Lack of low-pressure detectors to sample hydrogen supply and identify sources of impurities in production and distribution network.	2
	Determination of sampling frequency based on the effects of the impurity (i.e., degradation).	2
	Absence of detector device in the production and distribution process with specific focus on possible contaminants (i.e., upstream from CSD hardware).	2
	Need for low-pressure detectors for upstream operations (between production and CSD) and high-pressure detectors downstream (between CSD and dispensing to the vehicle).	2
	Determination of appropriate interface for detector (at the plant, nozzle, etc.) to detect contamination at various stages in production, delivery, and dispensing.	2
	Need for standardization of interfaces.	1
	Need for standardization of sampling methodologies.	1
	Lack of consensus on acceptability of a performance detector.	1
	Nonexistence of designs for robust and clean systems to avoid the need for detection instrumentation in the production and distribution process.	1
	Durability of potential hydrogen contamination detectors.	0
	Lack of agreement on the necessity of detectors present at the dispensing station.	0
	Potential for other low-level impurities to interfere with detector analysis.	0
	Lack of consensus on the range of impurities on which a detector should focus (i.e., one impurity? many?).	0
	Introduction of fuel quality clauses in fuel supply agreements.	0
	Need for agreement on proper placement of a detector (i.e., not downstream of compression).	0

Quality Control	Reliability and field maintenance of the detector/sensors.	2
	Need for definition of the practical composition of the fuel.	2
	Assurance of fuel quality in fuel supply agreements from fuel providers to HRS.	0
	Management of quality control process, methods, and instrumentation.	0
Programmatic Timelines	Need for accelerated, more aggressive timeline for development of HCDs.	4
	Lack of definition regarding long-term ultimate solution (i.e., in-line continuous monitoring of all relevant contaminants) and appropriate short-term efforts (i.e., definition of sampling and analytical requirements).	3
	Integration of on-site analytical capabilities: into automated sampling system; to enable analysis of manually collected samples.	2
	Lack of consideration of liquid hydrogen as a source at HRS.	2
Cost of Ownership	Potential for false positives to result in higher costs than the benefit received from deploying HCDs in HRS.	9
	Lack of interference-free or defined low-cost detectors for one or multiple species.	2
	Need for determination of a cost of ownership for HCDs that is acceptable by industry in the short-term.	1
	Need for consideration of station systems-level cost for detecting contaminants upstream of the vehicle (including CSD stages).	1
	Consideration of different cost elements of an HCD: cost per component, cost for all components, cost for target components.	0
	Lack of reporting protocol to FCEV owner regarding process and method when HCD detects contaminants in fuel.	0
	Need to deploy HCDs to increase economies of scale and reduce HCD cost (i.e., learning/ experience curves) as new technologies are developed.	0
	Achieving HCD/sensor system cost ($20,000- $30,000) of approximately 1% of the station CSD system ($2-$3 million).	0
	Differentiating short-term and long-term HCD needs and feasibility to minimize the impact of HCD deployment on station costs.	0

Among the highest priority challenges identified by each participant related to system specifications included the determination of sensitivity levels and identification of contaminants to be detected (6 votes); the need for frequency of analysis to reflect station location and utilization (6 votes); and the clarification regarding the purpose for HCDs and fuel quality analysis (i.e., process control versus quality assurance) (4 votes). Key challenges in the area of quality control centered around reliability and field maintenance of HCDs or related sensors (2 votes) and the definition of the practical, or ideal, composition of delivered hydrogen fuel (2 votes).

Programmatic timelines pose challenges to the definition of technical and performance requirements in that they were seen to be too conservative and not accelerated or aggressive enough for the timely development and deployment of HCDs (4 votes). Many participants identified a lack of clear definition regarding an ultimate long-term solution (i.e., in-line continuous monitoring of all relevant contaminants) and appropriate short-term efforts (i.e., definition of sampling and analytical requirements) (3 votes).

The highest priority challenge as identified by many participants was the potential for false positives to diminish the utility of the HCD in HRS (9 votes). A false positive reading in the detector may result in station down-time, missed hydrogen sales, and/or potentially unnecessary maintenance and repairs. This may pose a higher overall cost than the benefit that consumers receive from the assurance of quality hydrogen fuel and the high level of performance, durability, or improved lifetime for their FCEV that is enabled by an HCD at HRS. In addition, the lack of interference-free or low-cost detectors for one or multiple species is a clear gap in the currently available suite of devices. Industry experts also identified a need for the total cost of ownership of an HCD to be acceptable in the short-term (1 vote) and should consider the station systems-level cost for detecting contaminants upstream of the vehicle, including the CSD stages (1 vote).

Proposed Solutions and Strategies

The categories of challenges that were identified by each participant during the group session of the same name helped inform the categories of solutions presented below. Table 4 below presents the raw results of the group session, including a description of the ideas for recommended activities that the workshop participants suggested.

Table 4. Recommended Activities (Technical and Performance Requirements)

Solutions to Meeting Technical and Performance Requirements	
System Specifications	A detector capable of detecting CO at or below J2719 limits (near-term).
	Develop sampling requirements based on real-world conditions.
	Very precise analysis (even if high cost or off-site) necessary for installation or process changes.
	Form a panel to propose detector location and frequency of analysis.
	Detect main components that can do permanent damage, look at those levels of concentration not the lower levels. Many more solutions available. Fourier Transform Infrared spectroscopy (FTIR), methane dry reforming, computation reaction design, etc.
	Station providers should analyze systems and provide information on potential contaminants, locations of introduction, and duration.
	OEMs define minimum requirements (species, levels, and duration of exposure) that are unacceptable, assuming this will be less restrictive than J2719.
Quality Control	Best practices information for quality control at CSD stations.
	Evaluate current technology and compare against requirements. Deploy various existing HCD solutions at current H_2 filling stations for evaluation (accuracy, cost, reliability).
	Foray against quality issues through holistic approach detection, cleanliness, and improved reliability.
	Use probabilistic method for process control; establish procedure not to contaminate; identify suitable analysis.
	Identify, prioritize, and fund R&D of existing and promising detector concepts.
	Risk analysis to determine level of detection needed.
	Design flexible interface between station and analyzer.
	Analyze each fill at the nozzle.
	Store hydrogen in liquid form.

Timeline	Fund R&D towards long-term solution.
	Timeline needs to be aggressive. Support deployment of currently available viable technology (e.g., separations, commercial detectors, verification with ASTM methods, interface design).
	DOE issues a FOA or funds a lab call for development of a near-term HCD.
Cost	Low-cost CO detector for SMR upset alarm (small modular reactors).
	Extensive research into identifying practical false positives.
	False positive downstream of CSD shutting down station is worse than a false positive upstream of CSD; reduce impacts of false positives by only placing HCD upstream of CSD.
	Measurement of individual components may not be required. HCD would give value of overall impact on the fuel cell.
	With enough quality control upstream, a HCD may not be necessary at the HRS.
	Use enrichment devices to reduce cost of analyzers.

The solutions identified related to system specifications included: (1) developing a detector capable of detecting CO at or below J2719 limits (near-term); (2) developing sampling requirements based on real world conditions; (3) forming a panel to propose detector location and frequency of analysis; (4) detecting main components that can do permanent damage; (5) instructing station providers to analyze systems and provide information on potential contaminants; and (6) defining minimum requirements.

Proposed solutions in the area of quality control focused on developing best practices based on an evaluation of the current technology, conducting risk analysis, and designing a flexible interface between the station and the analyzer.

In terms of challenges in timeline, suggested solutions included funding R&D and supporting deployment of current technology in order to accelerate viable solutions. Regarding challenges in relation to cost, proposed solutions involved eliminating false positives, both by conducting research on potential causes as well as reducing the effects by only placing HCDs upstream of CSD.

Near-Term Solutions to Meet Deployment Requirements

This breakout session was moderated by Danny Terlip of NREL. The first discussion focused on identifying internal and external challenges to achieving near-term commercialization of HCD technologies. The second discussion focused on related activities and solutions for enabling the near-term commercialization of HCD technologies to help resolve the top challenges identified in the first exercise.

A specific set of questions from a previously released RFI on HCD development needs were presented as a means of focusing the brainstorming to extract targeted feedback from the attendees that were present. A cross-section of stakeholders chose to participate in this session, representing roughly half of the total number of the workshop attendees, which enable the workshop organizers to capture the most valuable set of input from relevant stakeholders. The questions addressed in this breakout session are listed below:

General Information on HCD Needs

- In what timeframe could the first HCD be deployed, recognizing the technology readiness level (TRL)? Please specify date and technical maturity (e.g., TRL).
- Should HCD technologies be advanced through continued R&D and periodically replaced with upgraded devices at fueling stations?
- Current Experience

- What types of fuel quality measurement devices are currently used at hydrogen stations? Are they sufficient?
- Is there current frequent or continuous fuel quality monitoring from hydrogen fueling stations? What fuel contaminants have been identified? To what level? What is the source of the contaminant?
- What other applications/industries (e.g., semiconductor manufacturing, food processing, etc.) may already use HCD or similar devices?

Participants each identified their top ideas for internal and external challenges to meeting the DOE objective, then shared them one idea at a time, until all ideas were exhausted.

The attendees each identified the challenges they perceived as important to meeting HCD deployment requirements in the near-term by indicating their top five choices. In the remainder of the breakout session, attendees brainstormed solutions to enable the near-term commercialization and deployment of HCDs. Proposed challenges and solutions were grouped into five categories: (1) performance, (2) cost, (3) deployment timeframes, (4) system integration, and (5) roles and responsibilities.

Challenges

Table 5 below presents a compilation of the results of the brainstorming sessions, including a description of the ideas and the number of attendees identifying potential challenges.

Table 5. Priority Near-Term Deployment Requirements

	Challenges to Meeting Near-Term Deployment Requirements	Number of attendees that identified challenge as important
Performance	Need for sensors to meet SAE J2719.	5
	Need for an HCD with minimum level of maintenance and calibration.	4
	Lack of standard and enforcement thereof with regards to installation of HCD devices.	3
	Lack of definition of HCD interface, placement, frequency of sampling, data required, and format for communication.	3
	Need for high-pressure sampling capability in the HCD.	2
	Absence of a station hydrogen quality sampling plan defining frequency of sampling, detection limits, and contaminants of interest.	2
	Need for definition of criteria contaminants, acceptable levels of contamination, and frequency of sampling.	2
	Definition of frequency of sampling by HCD.	1
	Lack of hydrogen component and system cleaning standards.	1
Cost	Cost and quantity of HCDs deployed in the field.	4
	Limiting consideration of HCD technologies to off-the-shelf options for detecting contaminants in on-site production.	2
	Lack of understanding of tradeoff between HCD, improved filters, and improved controls and cleanliness practices.	1
	Low-cost HCD deployed widely in the short-term.	0
	Cost of HCD device.	0

Timeframes	Need to deploy at least 1 HCD by mid-2016.	3
	Lack of understanding of the trade-offs that need to be made regarding the following: run-times and accuracy of results; cost and accuracy; level of maintenance and ease of operation.	2
	Need to deploy an HCD within one year.	0
System Integration	Consideration of alternative methods of detection such as more stringent quality control processes.	8
	Need for identification of optimal locations for HCD within a disparate system of components.	4
	Lack of definition regarding refueling system functionality (i.e., fuel flow) as a result of the detection of a contaminant.	2
	Ability for an HCD to provide a binary response to the fueling process (i.e., yes/no) rather than testing individual components for sources of contamination.	1
	Lack of particle filters in HRS.	0
Roles and Responsibilites	Lack of clear definition regarding the purpose of an HCD (e.g., fuel quality validation versus fueling process management).	10
	Need for consensus on substitutability of an HCD for upstream process QC measures.	4
	Need for an HCD to be implemented as a component of a broader QA/QC scheme to ensure quality.	3
	Determination of the appropriate body to test HCDs and fuel quality at HRS.	2
	Lack of identification of appropriate HCD methods and technologies for QC, including methods for certification.	1

Some challenges related to HCD performance that the participants identified as important included the need for HCDs to meet specifications of the J2719 Hydrogen Fuel Quality standard (5 votes); concerns about minimizing maintenance and calibration requirements for an HCD (4 votes); the lack of standardization and hence enforcement regarding installation of HCDs (3 votes); and the lack of definition of HCD interface, placement, frequency of sampling, data required, and format for communication (3 votes). Among the top priority challenges facing HCD cost were the cost and quantity of HCDs that should be deployed in the field (4 votes); limiting consideration to off-the-shelf options for detecting contaminants in on-site production (2 votes); and a lack of understanding regarding the trade-off between HCD, improved fuel filters, and improved controls and cleanliness practices (1 vote).

Among the challenges relating to timeframes for deployment, the highest priority was deemed as the need to deploy at least one HCD by mid-2016 (3 votes) and the lack of understanding of necessary trade-offs between the following: run-times and accuracy of results, cost and accuracy, and level of maintenance and ease of operations (2 votes). High priority challenges facing system integration include the consideration of alternative methods of detection (i.e., stringent quality control processes) (8 votes) and the need for identification of optimal placement for HCDs within a system of disparate components (4 votes).

The highest priority challenge of all proposed ideas in this breakout session was identified as the lack of clear definition regarding the purpose of an HCD (e.g., fuel quality validation versus fueling process management) (10 votes). This demonstrates an interest on behalf of industry stakeholders to further explore the desired functionality of such a device from a conceptual perspective. This also expresses attentiveness to the utility of a device that only validates fuel quality in real-time rather than one that can cleanse the fuel stream or halt the fueling process upon signaling that the fuel contains an unacceptable level of contaminants.

Other high priority challenges identified include the need for consensus regarding the substitutability of an HCD for upstream process QC measures (4 votes) and the desire for an HCD to be implemented not as the sole solution but as a component of a broader QA and/or QC scheme to ensure delivery of hydrogen fuel that meets J2719 specifications (3 votes).

Proposed Solutions and Strategies

Table 6 below presents a compilation of the results of the brainstorming sessions, including a description of the ideas for recommended activities identified by each participant.

Table 6. Recommended Activities (Near-Term Deployment)

Solutions to Meet Near-Term Deployment Requirements	
Performance	Existing technologies (e.g., FTIR) can perform continuous monitoring of CO, CO_2, CH_4, H_2O at under 50 ppb with a 1 minute sample time in hydrogen.
	Quality Assurance: cost-effective sampling process.
	Quality Control: on-site, real-time process control methods and technologies.
	Clearly defined mitigation strategies focused around methods of QC.
	Development of a fuel quality database to track station performance for all existing stations.
	Development of cost and performance data matrix for existing HCD technologies to inform short-term options and long-term needs.
	Development of a gas sensor for detecting contaminants in hydrogen with a rapid response time.
	Shift in focus from end-user station QC measures to determination of QA requirements.
	Monitoring, per system requirements, to assure SAE J2719 quality is met at stations does not equate to monitoring at SAE J2719 levels.
Cost	Low-cost CO detector for hydrogen supply to CSD systems.
	Cost limited to 1% of total station capital expenditures.
Timeframes	Deploy current off-the-shelf technologies to assure and improve performance – further R&D is not needed.
	Acceleration of fuel cell concept R&D.
	Quarterly maintenance requirements for HRS.

System Integration	Development of an appropriate analyzer based on engineering review of fueling system.
	Incorporation of an HCD into the fueling system based on the hydrogen source with periodic sampling at the hydrogen dispenser hose.
	Full SAE J2719 grab analysis for verification of installation and process changes.
	Development of a simple screening device to screen for total contaminant levels in the hydrogen fuel stream.
	Risk analysis for determination of necessary level of contaminant detection from HCD or other measures.
	Investigate existing and potential analytical technologies and measures which should be the highest priority for development and commercial deployment.
	Re-examination of existing analytical apparatus to identify appropriate points of analysis within the production and delivery system.
	Tightened upstream QC measures for gas truck delivery may negate the need for an HCD at the station.
Roles and Responsibilities	Require OEMs and station providers to agree on QA/QC policies for all stations.
	Delineation of supplier responsibilities regarding purity and readiness of delivered hydrogen.
	Agreement on and determination of fueling station responsibilities including the provision of contaminant-free fuel to end-users.
	Presuming fueling station responsibilities for contaminant-free fuel delivery, stations should determine the location, frequency, and detection limit of an HCD.
	Test frequency should be determined by regulators (i.e., California Division of Measurement Standards) with expert input.

A number of high-priority activities were identified by participants during the near-term deployment requirements breakout session. Common themes and similar ideas from participants in the breakout session helped identify activities and approaches of high importance that are perceived to have a significant value for informing technology development and deployment strategies and pathways.

In the area of HCD performance, key points of discussion included the currently available HCD technologies though they may not be sufficient or cost-effective enough to satisfy the current needs identified by OEMs, gas providers, and station developers. This session also included a suggestion for developing a cost and performance data matrix to take inventory and enable comparison between existing HCD technologies and inform short-term options and long-term needs. Such a framework would complement another proposed solution of a fuel quality database that tracked existing station performance. Other themes of interest focused on the definition of strategies and QA/QC methods and technologies, specifically in shifting the focus away from end-users to determining more pro-active QA requirements and methods.

Suggested activities related to cost involved the development of a low-cost CO detector for integration in CSD systems upstream of the fueling nozzle. In addition, one participant proposed that the capital cost of an HCD be limited to no more than 1% of total station capital expenditures. Solutions regarding the deployment timeframes were centered around three separate ideas, indicating a lack of consensus on the most appropriate approach moving forward. The proposed activities included deployment of current off-the-shelf technologies as opposed to further R&D; quarterly maintenance requirements for HRS; and acceleration of fuel cell concept (i.e., “canary device”) R&D.

Recommended solutions for system integration were disparate and provided a range of options for immediate action as well as options for consideration in the mid-term. An engineering review of the fueling system was suggested as a possible activity which would provide synergistic benefits if this informed the most appropriate location for the placement of an HCD device within the fueling system. In addition, more stringent upstream QC measures, specifically for gas truck delivery, may negate the need for an HCD at the station. In the interim, there was interest in performing risk analysis to determine the appropriate level of contaminant detection from an HCD or other contaminant detection measures.

Lastly, the proposed activities for solving challenges related to roles and responsibilities of key stakeholders revolved around more clearly defined and delineated responsibilities among key stakeholders such as fueling station operators and fuel suppliers. Solutions also focused on improving the consensus among the relevant stakeholder community regarding their roles in the provision and implementation of QA/QC policies and the location, frequency, and detection limit of an HCD.

Long-Term R&D Areas to Address Technical Gaps

This breakout session was moderated by Terry Johnson of Sandia National Laboratories and focused on the challenges to the detection of contamination at HRS that can be implanted through long-term R&D (referring to 2017 and beyond).

Several questions from a previously released RFI were presented as a means of focusing the brainstorming to extract targeted feedback from the attendees that were present. The questions are listed below:

Device R&D/Potential Solutions

- Could a "canary" device (for example a fuel cell-based device) be used as an HCD to trigger fuel shut-off and protect fuel cell vehicles? What "canary" HCD technologies exist or could be developed? What contaminants would be problematic for this technology (e.g. with regard to response time or sensitivity).
- Are there any opportunities to develop a device that detects the presence of ANY impurities in hydrogen without identifying them (as opposed to a device that detects presence of specific pre-defined deleterious contaminants)? Are there any impurities that do not cause degradation to the fuel cell or vehicle operation that could cause false alarm?

Participants identified their top ideas for internal and external challenges to meeting the DOE goal then shared them, one idea at a time, until all ideas were exhausted.

The attendees identified the challenges they perceived as important by indicating their top three choices. In the remainder of the breakout session, attendees brainstormed R&D needs and solutions to address the top challenges. Proposed solutions were grouped into six categories: (1) current technology and future research, (2) requirements, (3) concentration, (4) cost, (5) technical, and (6) sampling.

Challenges

Table 7 below presents a compilation of the results of the brainstorming sessions, including a description of the ideas and the number of attendees identifying potential challenges.

Table 7. Priority Technical Gaps

Long-Term R&D Areas to Address Technical Gaps		Number of attendees that identified challenge as important
Technical	Lack of R&D for monitoring devices to improve sensitivity and response time.	1
	Need for system that can verify compliance with J2719.	1
	Response time should be improved.	0
	Need to determine whether a single platform (optical, microfluidic sensing) meets an acceptable number of targets.	0
	Guarding against a false positive should be a priority.	0
	Research high-pressure (guard bed) purities to minimize impurities.	0
Sampling	Need to determine how to define/design a flexible/useful interface sampler.	1
	Lack of simple sample equipment; possible methods to concentrate samples; verification/improvement of sampling gas, particulates.	1
	Determine whether there is need for work here. Any evidence that current methods are inadequate.	0
Sensor Reliability	Lack of tests for evaluating long-term robustness and reliability for new technologies.	4
	Lack of reliability and durability.	0
Current Technology	Need to assess state of detector concepts then plan further development.	2
	Multiple application process control, remote sample ability, and transportability.	0
	Determine commercial market projection for a device.	0
Concentration	Integrate enrichment devices with detectors to enable low detection limits.	4
	Need to determine whether a concentration device can be built to take a sample at the nozzle and if a concentrated sample can be analyzed by a fuel cell.	1
	Concentration—separate H_2 to concentrate impurities; could be pressure saving and absorb impurities.	0
Cost	Need to explore whether or not on-site methods can be implemented that meet SAE 2719 requirements in a cost effective way (e.g. that is <5% of station cost).	1
	Lack of low-cost "canary" species detectors (i.e., fuel cell based device), lower-cost analytic equipment.	0
	Need to determine a benchmark cost of device based on current technology.	0
	Need for simplicity and easy maintenance; low/no maintenance; low or no calibration requirements.	0
Particulates	Need to take a particulate sample at nozzle and visually examine filter.	1

The highest priority challenges related to concentration included the need to integrate enrichment devices with detectors to enable low detection limits (4 votes), as well as uncertainty as to whether a device can be built to take a sample at the nozzle (1 vote). Identified challenges regarding technical considerations included the need for improvement in device sensitivity and response time (1 vote) and a lack of verification of compliance with SAE J2719 (1 vote).

In terms of current technology, participants cited the main challenge as the need to first assess the state of detector concepts before planning further development (2 votes). Cited challenges in sampling included the need to design a flexible, useful sampling interface (1 vote) and the need for increased R&D for improving the sampling process in general (1 vote). The main challenge relating to cost was the need to explore whether or not on-site methods that meet SAE J2719 requirements can be implemented in a cost-effective way (1 vote).

Participants identified the highest priority challenge in sensor reliability as lack of robustness and reliability within the new technology (4 votes). Without sensor dependability, it is difficult to encourage widespread device implementation.

Proposed Solutions and Strategies

Table 8 below presents a compilation of the results of the brainstorming sessions, including a description of the ideas for recommended activities identified by each participant.

Table 8. Recommended Activities (Long-Term R&D Areas)

Long-Term R&D Areas to Address Technical Gaps	
Current Technology & Future Research	Evaluate various potential HCD solutions in HRS over the next few years.
Requirememts	Assign a panel to evaluate needs, options, and recommend strategy for a team of organizations to pursue.
	Develop a requirement document available to industry to guide development.
	Generate a product standard to address safety, operation, operating claims (similar to Underwriters Laboratories standard 2075 - Standard for Gas and Vapor Detectors and Sensors).
Concentration	Validate methods of concentration of species (validate claims independently).
	Concentration—fill inner tank to 10 kgs; inner tank permeable to H_2 not to other gases; regulate outer tank to 100 psi so inner tank drops to 100 psi of concentrated impurities; test contents of inner tank.
Cost	Reduce cost of high-priced technology.

Technical	Invest in R&D for contaminant monitoring for 1) potential to certify to J2719 and 2) canary species CO, H_2S detection.
	Develop low-cost/low-pressure Reomon 7 option (sensor sees 150 psi rather than 10,000 psi).
	Low-cost, low-pressure detector.
	Advanced integrated concentrator detector station system.
	Field test enrichment/detection hardware.
Sampling	Set sampling protocol.
	Collect data on sampling techniques (ASTMs) and verify the procedure is practical; work with manufacturer's sample cylinders to develop and field a commercial off-the-shelf sampling device (gas, particulate, metrology).

The top solutions related to detection limits involved validating concentration methods based upon the contaminant species. Identified solutions regarding technical considerations included investing in research for contaminant monitoring and field tests as well as developing low-cost and low-pressure detector technology.

Participants cited the importance of determining the ideal sampling techniques and setting sampling protocol. Setting HCD requirements was identified as a high priority solution. In order to effectively address the established challenges, participants suggested that a panel further evaluate R&D needs and develop a guidance document available within the industry.

Conclusion

Given the imminent rollout of FCEVs in the U.S., there is a clear need for HCD technologies and measures to ensure that delivered hydrogen fuel is compliant with SAE standard J2719. Currently available HCD and similar technologies do not meet the technical, performance, or cost requirements that are desired for an HCD to be deployed on a large scale at HRS. Although there is a lack of consensus regarding the most effective and low-cost approach to implementing such technologies, there is a common understanding among stakeholders with respect to the trade-off between cost, accuracy, performance, device placement within the system, and other key parameters. Additional effort is needed to determine the appropriate sensitivity level of an HCD, the frequency of sampling, and feedback mechanism to the consumer at the fueling system. Aside from the technical and performance parameters, experts identified the need for a multi-faceted approach to contamination detection in the near-term, given the limitations of resource constraints on public and private sector organizations. For this reason, an HCD was considered as one element of a broader solution to the challenge of ensuring delivery of J2719-compliant hydrogen fuel. Long-term solutions might include implementation of more stringent QA/QC measures, both upstream and downstream in the hydrogen fuel supply chain.

The greatest concern in terms of long-term R&D and technical gaps was determining the best way to integrate enrichment devices with detectors to enable low detection limits. Another prominent concern was ensuring the reliability and robustness of long-term tests. Attendees also emphasized the importance of evaluating current technology and conducting rigorous research before setting R&D priorities. Another proposed solution would assign a panel to evaluate needs; recommend strategies; and generate HCD industry standards and requirements. In addition, participants suggested collecting data on sampling techniques and developing a practical sampling protocol.

The workshop yielded valuable input from individual participants, including a range of targeted solutions to address near-term and long-term challenges. A multi-faceted approach is considered the most appropriate solution in the near-term given resource constraints and the availability of existing technologies and QA/QC measures. In the long-term, further guidance is needed by experts to inform and prioritize R&D for more sufficient and technologically advanced detection devices and analytical methods that can better serve the needs of key stakeholders. This will reflect the changing need for HCDs as FCEVs increasingly penetrate vehicle markets and infrastructure expands to meet the needs of the sustainable transportation sector in the U.S.

Appendix A: Abbreviations and Acronyms

Ar – argon

ASTM – American Society for Testing and Materials

CH_4 – methane

CO – carbon monoxide

CO_2 – carbon dioxide

CSD – compression, storage, and dispensing

DOE – U.S. Department of Energy

FCEV – fuel cell electric vehicle

FCTO – Fuel Cell Technologies Office

FOA – Funding Opportunity Announcement

FTIR – Fourier Tranform Infrared spectroscopy

H_2 – hydrogen

H_2O – water

H_2S – hydrogen sulfide

HCD – hydrogen contamination detector

He – helium

HRS – hydrogen refueling station

LANL – Los Alamos National Laboratory

N_2 – Nitrogen

NREL – National Renewable Energy Laboratory

ppb – parts per billion

psi – pounds per square inch

QA – quality assurance

QC – quality control

R&D – research and development

RD&D – research, development and demonstration

RFI – Request for Information

SAE – Society of Automotive Engineers

SMR – steam-methane reforming

TIR – technical information report

TRL – Technology Readiness Level

Appendix B: Workshop Announcement and Agenda

Hydrogen Contamination Detector Workshop

DOE Fuel Cell Technologies Office
Hosted by:
SAE International, Troy, Michigan
June 12, 2014
(8:30 AM – 3:00 PM)

Workshop Objective:

The objective of the Hydrogen Contamination Detector (HCD) Workshop is to gather input from stakeholders on requirements, technologies and the research and development (R&D) gaps associated with the detection of contamination at hydrogen fueling stations. This input will help identify current state-of-the-art detection technologies for the near-term and the R&D advancements needed for low-cost, accurate, and robust detectors for the long-term.

Desired outcomes include:

- Summary of technical and performance requirements for hydrogen contamination detectors
- Summary of existing and potential contaminant detection devices
- Summary of key gaps for long-term contaminant detector research and development
- Workshop report to publically disseminate findings

Tentative Agenda:

8:30 am	Opening Remarks, *Will James, U.S. Department of Energy*
8:45 am	Current Fuel Quality Challenges 15 mins. – Auto OEM, *Tim McGuire, Mercedes-Benz R&D North America, Inc* *Mike Steele, Consultant* 15 mins. – Station Operator, *Herie Soto, Shell*
9:15 am	Introduction to Existing and Potential Contaminant Detection Devices and Associated R&D Needs (Near- and Long-Term) • Deployment Requirements – *Bill Buttner, National Renewable Energy Laboratory* • Specialized Applications – *Andrew Kaldor, Power+Energy* • R&D Sensing Techniques – *Rangachary Mukundan, Los Alamos National Laboratory* • Laboratory Applications – *JP Hsu, Smart Chemistry*
10:15 am	Break
10:45 am	Discussion: Technical and Performance Requirements for Detection of Fuel Quality at the Station (Facilitator: Scott McWhorter, Savannah River National Laboratory) - Detector Performance Requirements (e.g., response time, sensitivity, etc.) - Refueling System Integration Requirements (where, what action results, mechanical connections, etc.) - Hydrogen Contaminant Detection Device
12:00 pm	Lunch
1:15 pm	Breakout Sessions on Near- and Long-Term Solutions A. Near-Term Solutions to Meet Deployment Requirements (Facilitator: Danny Terlip, NREL) B. Long-Term R&D Areas to Address Technical Gaps (Facilitator: Terry Johnson, NREL)
2:45 pm	Brief Report-Outs and Wrap-Up
3:00 pm	Adjourn

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Appendix C: Participant List

Shabbir Ahmed – *Argonne National Laboratory*

Jacquelyn Birdsall – *Toyota Motor Engineering & Manufacturing NA Inc.*

Nico Bouwkamp – *California Fuel Cell Partnership*

Robert W. Boyd – *Boyd Hydrogen LLC*

Edward Bramston-Cook – *Lotus Instruments*

Dave Brokaw – *Bruker Instruments*

William Buttner – *National Renewable Energy Laboratory*

William P. Collins – *Independent Consultant*

Gerhard Gissibl – *BMW Munich*

Aaron Harris – *Air Liquide NA*

Matsuo Hiranom – *Power+Energy*

JP Hsu – *Smart Chemistry*

Will James – *U.S. Department of Energy*

Praveen Jha – *Matheson Gas*

Terry Johnson – *Sandia National Laboratories*

Andrew Kaldor – *Power+Energy*

Jay Keller – *Independent Consultant*

Jon Kilborn – *Horiba Instruments*

Julia Kittel – *Energetics Inc.*

Kristian Kiuru – *Energetics Inc.*

Jason Marcinkoski – *U.S. Department of Energy*

Barbara Marshik-Geurts – *MKS*

Steve Mathison – *Honda North America R&D*

Timothy McGuire – *Mercedes-Benz R&D NA Inc.*

Scott McWhorter – *Savannah River National Laboratory*

Rangachary Mukundan – *Los Alamos National Laboratory*

Spencer Quong – *Quong and Associates*

Glenn W. Scheffler – *Independent Consultant*

Herie J. Soto – *Shell*

Eugene M. Steele – *Independent Consultant*

Jean St-Pierre – *Hawaii National Energy Institute*

Hidenori Tomioka – *Japan Automobile Research Institute*

Danny Terlip – *National Renewable Energy Laboratory*

Michael J. Veenstra – *Ford Motor Co.*

Appendix D: Request for Information (RFI)

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

Hydrogen Contamination Detectors

DE-FOA-0001116

DATE: 04/22/2014

SUBJECT: Request for Information (RFI) on hydrogen contamination detectors (HCDs).

DESCRIPTION: The Department of Energy's (DOE) Fuel Cell Technologies Office (FCTO) seeks feedback from stakeholders on existing and potential hydrogen contamination detectors and related factors such as performance characteristics, system integration requirements, costs, deployment guidance, and R&D needs.

BACKGROUND: The FCTO is a key component of the DOE's Energy Efficiency and Renewable Energy (EERE) portfolio. EERE seeks to provide clean, affordable, and reliable energy from diverse domestic resources, along with benefits of increased energy security, reduced criteria pollutants and reduced greenhouse gas emissions. Light-duty vehicles and fueling components are a major emphasis of FCTO's RD&D portfolio. Between 2004 and 2012, FCTO's National Fuel Cell Electric Vehicle Learning Demonstration project deployed and collected data on over 180 fuel cell vehicles and 25 hydrogen fueling stations; and in 2013 the Department initiated several new projects to continue collecting data on fuel cell vehicles and hydrogen stations.

With several plans announced for the introduction of fuel cell vehicles in the 2015 to 2020 timeframe and several new hydrogen stations currently breaking ground, it is important to manage the risk associated with contaminated hydrogen. DOE is considering pro-active strategies to mitigate the risk of fuel contamination. Specifically, DOE is exploring the use of HCDs at fueling stations to halt fuel dispensing if hydrogen quality is compromised to protect fuel cell vehicles from damage while the source of contamination is identified and eradicated.

PURPOSE: The purpose of this RFI is to seek input from stakeholders on methods, requirements and technologies for the detection of hydrogen contamination resulting from an equipment or process failure at fueling stations that would normally meet fuel specification. An HCD will be used to prevent potential degradation of fuel cell vehicles, which can be sensitive to fuel contamination. The purpose is NOT to comment on devices for analyzing hydrogen fuel quality to meet requirements of SAE J2719 and ISO 14687-2. Fuel quality certification and station qualification are considered separate processes. The development of inexpensive detectors to meet SAEJ2719 and ISO 14687-2 would be a mid- to long-term activity.

In this RFI, we seek feedback on the compromise between requirements for: timeframe for deployment, capabilities, and cost, recognizing that near-term solution is required for 2015 deployments, and that the cost to provide protection should not outweigh the potential costs associated with fuel cell vehicle contamination. In addition to near-term solutions, the DOE also seeks feedback on longer-term R&D for improving the technology for later deployment (after 2017). This input will help identify low-cost, accurate, and robust detection equipment and any necessary research and development (R&D) associated with them. This is solely a request for information and not a Funding Opportunity Announcement (FOA). EERE is not accepting applications.

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This is a Request for Information (RFI) only. EERE will not pay for information provided under this RFI and no project will be supported as a result of this RFI. This RFI is not accepting applications for financial assistance or financial incentives. EERE may or may not issue a Funding Opportunity Announcement (FOA) based on consideration of the input received from this RFI.

DISCLAIMER AND IMPORTANT NOTES: Any information obtained as a result of this RFI is intended to be used by the Government on a non-attribution basis for planning and strategy development; this RFI does not constitute a formal solicitation for proposals or abstracts. Your response to this notice will be treated as information only. EERE will review and consider all responses in its formulation of program strategies for the identified materials of interest that are the subject of this request. EERE will not provide reimbursement for costs incurred in responding to this RFI. Respondents are advised that EERE is under no obligation to acknowledge receipt of the information received or provide feedback to respondents with respect to any information submitted under this RFI. Responses to this RFI do not bind EERE to any further actions related to this topic.

PROPRIETARY INFORMATION: Because information received in response to this RFI may be used to structure future programs and FOAs and/or otherwise be made available to the public, **respondents are strongly advised to NOT include any information in their responses that might be considered business sensitive, proprietary, or otherwise confidential.** If, however, a respondent chooses to submit business sensitive, proprietary, or otherwise confidential information, it must be clearly and conspicuously marked as such in the response.

Responses containing confidential, proprietary, or privileged information must be conspicuously marked as described below. Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise. The U.S. Federal Government is not liable for the disclosure or use of unmarked information, and may use or disclose such information for any purpose.

If your response contains confidential, proprietary, or privileged information, you must include a cover sheet marked as follows identifying the specific pages containing confidential, proprietary, or privileged information:

> **Notice of Restriction on Disclosure and Use of Data:**
> Pages [list applicable pages] of this response may contain confidential, proprietary, or privileged information that is exempt from public disclosure. Such information shall be used or disclosed only for the purposes described in this RFI DE-FOA-0001116. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.

In addition, (1) the header and footer of every page that contains confidential, proprietary, or privileged information must be marked as follows: "Contains Confidential, Proprietary, or Privileged Information Exempt from Public Disclosure" and (2) every line and paragraph containing proprietary, privileged, or trade secret information must be clearly marked with double brackets or highlighting.

EVALUATION AND ADMINISTRATION BY FEDERAL AND NON-FEDERAL PERSONNEL: Federal employees are subject to the non-disclosure requirements of a criminal statute, the Trade Secrets Act, 18 USC 1905. The Government may seek the advice of qualified non-Federal personnel. The Government may also use non-Federal personnel to conduct routine, nondiscretionary administrative activities. The respondents, by submitting their response, consent to DOE providing their response to non-Federal parties. Non-Federal parties given access to responses must be subject to an appropriate obligation of confidentiality prior to being given the access. Submissions may be reviewed by support contractors and private consultants.

REQUEST FOR INFORMATION AREA OF INTEREST AND QUESTIONS: FCTO seeks your input on implementation strategies for HCDs so that it may plan appropriate RD&D activities in support of industry-led efforts or resulting codes and standards concerning national hydrogen infrastructure deployment. Please provide overall ideas, strategies or plans for mitigating the risks associated with hydrogen fuel contamination. Include timing, requirements, technologies and costs. We welcome comment on relevant issues not identified in the following questions.

The FCTO will be interested in guidance on this topic area, through responses to the following questions:

GENERAL

1. In what timeframe could the first HCD be deployed, recognizing the technology readiness level (TRL)? Please specify date and technical maturity (e.g., TRL). See Table 1 in Response Guidelines section below for the explanation of TRL levels.
2. Should HCD technologies be advanced through continued R&D and periodically replaced with upgraded devices at fueling stations?

CURRENT EXPERIENCE

3. What types of fuel quality measurement devices are currently used at hydrogen stations? Are they sufficient?
4. Have you conducted frequent or continuous fuel quality monitoring from hydrogen fueling stations? What fuel contaminants have you identified? What level? Have you identified the source of the contaminant? Have you correlated any of the contaminants found with fuel cell stack degradation?
5. What other applications/industries (e.g. semiconductor manufacturing, food processing, etc.) may already use HCD or similar devices?
6. Provide a list of companies that produce (or are developing) HCD or HCD-type devices.

HCD REQUIREMENTS

7. What aspects of HCD mechanical and electrical interfaces should be standardized? Should connection standards be developed so detectors can be upgraded or replaced easily?
8. What is the maximum allowable cost for an HCD solution to be economical?
9. Where do HCDs need to be positioned with respect to station components?
10. For each of the following questions, please be sure to specify the position of the proposed device (for potential solutions including multiple detector types in various positions).
    a. Specify the contaminants that should be detected. What is the source of the contaminant? How severe is the impact on the fuel cell?
    b. For each contaminant, what is the minimum sensitivity a device would need to have in order to provide a useful response to the contaminant (for near-term deployment)?
    c. For each contaminant, what should the target sensitivity of the device be for longer-term R&D.
    d. What devices can be used to detect each contaminant? Which is best and why?
    e. What would the detection device cost? How often would they need to be re-calibrated or replaced? What is the response time?

DEVICE R&D / POTENTIAL SOLUTIONS

11. Could a "canary" device (for example a fuel cell-based device) be used as an HCD to trigger fuel shut-off and protect fuel cell vehicles? What "canary" HCD technologies exist or could be developed? What contaminants would be problematic for this technology (e.g. with regard to response time or sensitivity).

12. Are there any opportunities to develop a device that detects the presence of ANY impurities in hydrogen without identifying them (as opposed to a device that detects presence of specific pre-defined deleterious contaminants)? Are there any impurities that do not cause degradation to the fuel cell or vehicle operation that could cause false alarm?

OTHER CONSIDERATIONS

If there is a topic or consideration you'd like to add to this list, please include it in your response.

REQUEST FOR INFORMATION RESPONSE GUIDELINES: Responses to this RFI must be submitted electronically to H2ContaminationRFI@ee.doe.gov no later than 5:00pm (EDT) on May 19, 2014. Responses must be provided as a Microsoft Word (.docx) attachment to the email, of no more than 4 pages in length, 12 point font, 1 inch margins. Only electronic responses will be accepted. Respondents may answer as many or as few questions as they wish.

EERE will not respond to individual submissions or publish publicly a compendium of responses. A response to this RFI will not be viewed as a binding commitment to develop or pursue the project or ideas discussed.

Respondents are requested to provide the following information at the start of their response to this RFI:

- Company / institution name;
- Company / institution contact;
- Contact's address, phone number, and e-mail address.

Table 1: Technology Readiness Level Definitions

Technology Readiness Level	Level Definition
TRL 1	**Basic Research.** Initial scientific research begins. Examples include studies on basic material properties. Principles are qualitatively postulated and observed.
TRL 2	**Applied Research.** Initial practical applications are identified. Potential of material or process to satisfy a technology need is confirmed.
TRL 3	**Critical Function, i.e., Proof of Concept Established.** Applied research continues and early stage development begins. Includes studies and initial laboratory measurements to validate analytical predictions of separate elements of the technology. Examples include research on materials, components, or processes that are not yet integrated.
TRL 4	**Laboratory Testing/Validation of Alpha Prototype Component/Process.** Design, development and lab testing of technological components are performed. Results provide evidence that applicable component/process performance targets may be attainable based on projected or modeled systems.
TRL 5	**Laboratory Testing of Integrated/Semi-Integrated System.** Component and/or process validation in relevant environment- (Beta prototype component level).
TRL 6	**Prototype System Verified.** System/process prototype demonstration in an operational environment- (Beta prototype system level).
TRL 7	**Integrated Pilot System Demonstrated.** System/process prototype demonstration in an operational environment-(integrated pilot system level).
TRL 8	**System Incorporated in Commercial Design.** Actual system/process completed and

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TRL 8	**System Incorporated in Commercial Design.** Actual system/process completed and qualified through test and demonstration- (Pre-commercial demonstration).
TRL 9	**System Proven and Ready for Full Commercial Deployment.** Actual system proven through successful operations in operating environment, and ready for full commercial deployment.

This is a Request for Information (RFI) only. EERE will not pay for information provided under this RFI and no project will be supported as a result of this RFI. This RFI is not accepting applications for financial assistance or financial incentives. EERE may or may not issue a Funding Opportunity Announcement (FOA) based on consideration of the input received from this RFI.

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