Hydrogen Infrastructure Market Readiness Workshop: *Preliminary Results*

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Distributed electronically to workshop attendees for review

March 24, 2011

Goal of this presentation

- This presentation is being disseminated to workshop attendees to convey the aggregate and “raw” feedback collected during the workshop
- This feedback will be compiled in a final report
- We would like to accomplish two things with these slides:

1. **Share the preliminary results with participants**
2. **Get your feedback now on any corrections or omissions**

- We are still open to receiving additional feedback on the workshop topic, but will report it as having been received outside of the workshop if it is included in the final report
- Ideally, we will also get feedback and suggestions for revision on a draft version of the final report

Presentation Overview

1) INTRODUCTION
2) WORKSHOP PROCESS
3) SUMMARY OF COST REDUCTION OPPORTUNITY PRIORITIES
4) RAW FEEDBACK COLLECTED FROM WORKSHOP

INTRODUCTION

Preliminary Feedback Results

- The results shown here are preliminary, and should not be cited or referenced
- To provide feedback on these results, contact Marc Melaina at marc.melaina@nrel.gov
- A final report will be prepared and a draft version will be distributed for review

Workshop Goal

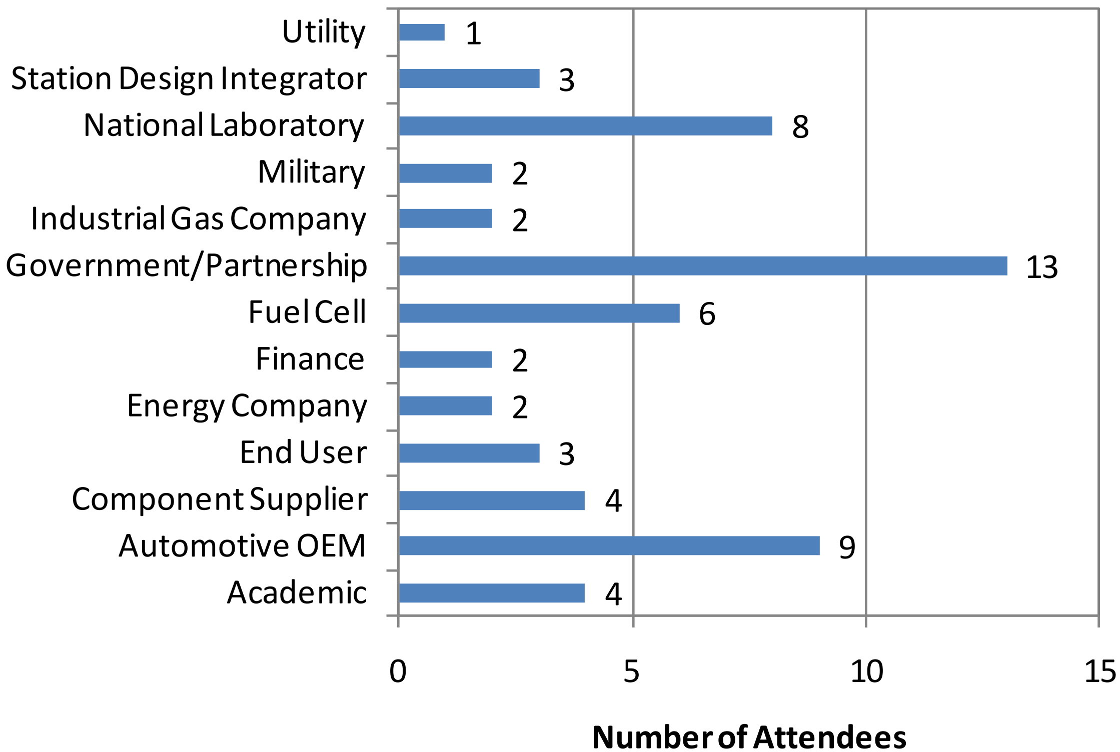
The goal of the workshop is to identify and collect feedback from key stakeholders on the following:

- Cost reduction opportunities from economies of scale (e.g., station standardization, number and size of installations) and learning-by-doing resulting from growth in material handling equipment (MHE), backup power, transit bus and light duty vehicle markets.
- Cost reduction opportunities from focused R&D areas and priorities.
- Specific examples through which early markets, such as MHE, backup power, and transit buses, can provide increased demand and reduce hydrogen infrastructure costs.

Key stakeholders are those who have been directly involved in the planning, funding and installation of hydrogen stations

Workshop Attendees

- Invitations were extended to over 260 experts
- 61 Attendees participated in panels discussions and breakout groups
- Diverse representation of multiple stakeholder types



WORKSHOP PROCESS

Panel Discussion #1 on Day One

Early Market End User Experiences (2:15-3:15 PM, Feb 16th)

Moderator: Pete Devlin, U.S. Department of Energy

- Roberto Cordaro, Nuvera
- Jamie Levin, AC Transit
- Alex Keros, General Motors
- Kevin Kelly, Sprint

Panel Questions

1. Based upon your experience with recent projects, what are the biggest costs and the biggest cost reduction opportunities for hydrogen stations?
2. What “hidden” costs emerged in your projects? What unexpected benefits did you achieve?
3. In hindsight, what could you have done to reduce costs incurred during the installation process? For example: contracting, planning, permitting, etc.
4. What government support mechanisms were most effective or would have been most effective in your project?

Panel Discussion #2 on Day One

Outlook for Infrastructure Cost Reductions (3:30 -4:30 PM, Fe

Moderator: Matt Fronk, Matt Fronk & Associates LLC

- Nikunj Gputa, Shell
- Steve Eckhardt, Linde
- Joan Ogden, University of California Davis
- Ed Heydorn, Air Products
- James Cross, Nuvera

Panel Questions

1. What do you consider the most significant cost driver for hydrogen stations today, and what needs to be done to overcome it?
2. How can improved technology bring down the cost of delivered hydrogen in the next 2-5 years? What's needed to achieve these technology advancements?
3. What are the major institutional or contractual barriers to deploying low-cost production technologies, delivery methods and adequately sized hydrogen stations in the next 2-5 years?
4. What are the major barriers to realizing a business case for hydrogen stations and infrastructure within the next 2-5 years?

Breakout Groups on Day Two

- Three groups of ~20 stakeholders were identified, with each group including multiple stakeholder types
- Each group was taken through the same breakout group process and questions.
- Key Focus Questions included the following:

1. What are the biggest opportunities to reduce the costs of hydrogen fueling stations over the next 2-5 years?
2. What can we DO to achieve the high-priority cost reduction opportunities?
3. DRILL DOWN for high priority opportunities (identified through a group voting process):

   Who needs to do what when? What kind of help is needed? Is information sharing or coordination needed?

Supporting Activities

Two additional outreach activities are underway to augment feedback received during the workshop

Coordination with ongoing activities

- CaFCP Roadmap to a commercial station

Early Station Cost Calculator

- Will be circulated to key stakeholders for review
- Responses will be compiled anonymously

SUMMARY OF COST REDUCTION OPPORTUNITY PRIORITIES

Prioritization process

Metric #1: Number of opportunities

- 137 cost reduction opportunities collected from panels and breakout groups (including duplication)

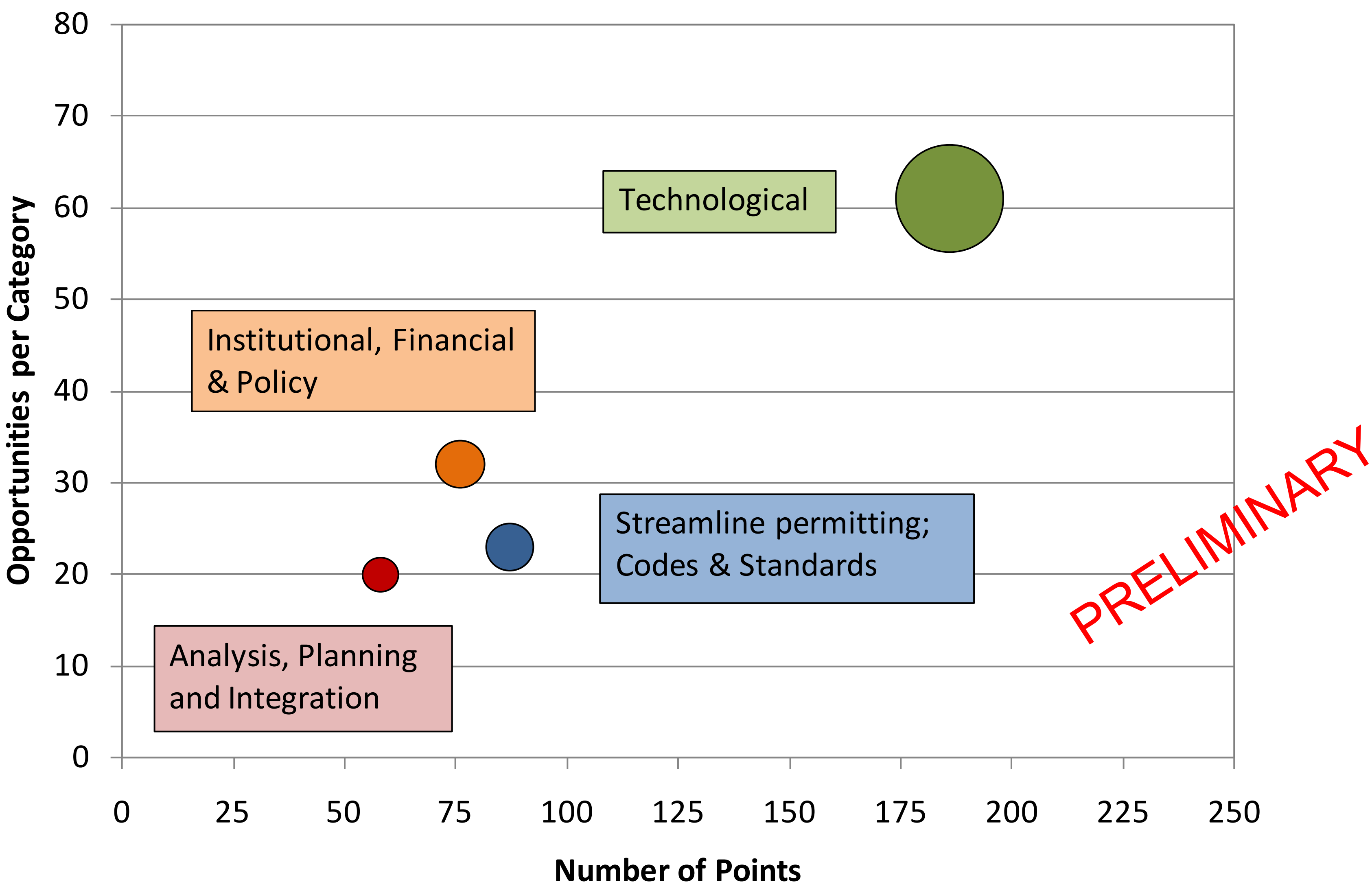
Metric #2: Point system

- Each panel opportunities assigned 2 points
- Each breakout group opportunity assigned 1 point, plus all additional points from group dot voting process

Aggregation by category

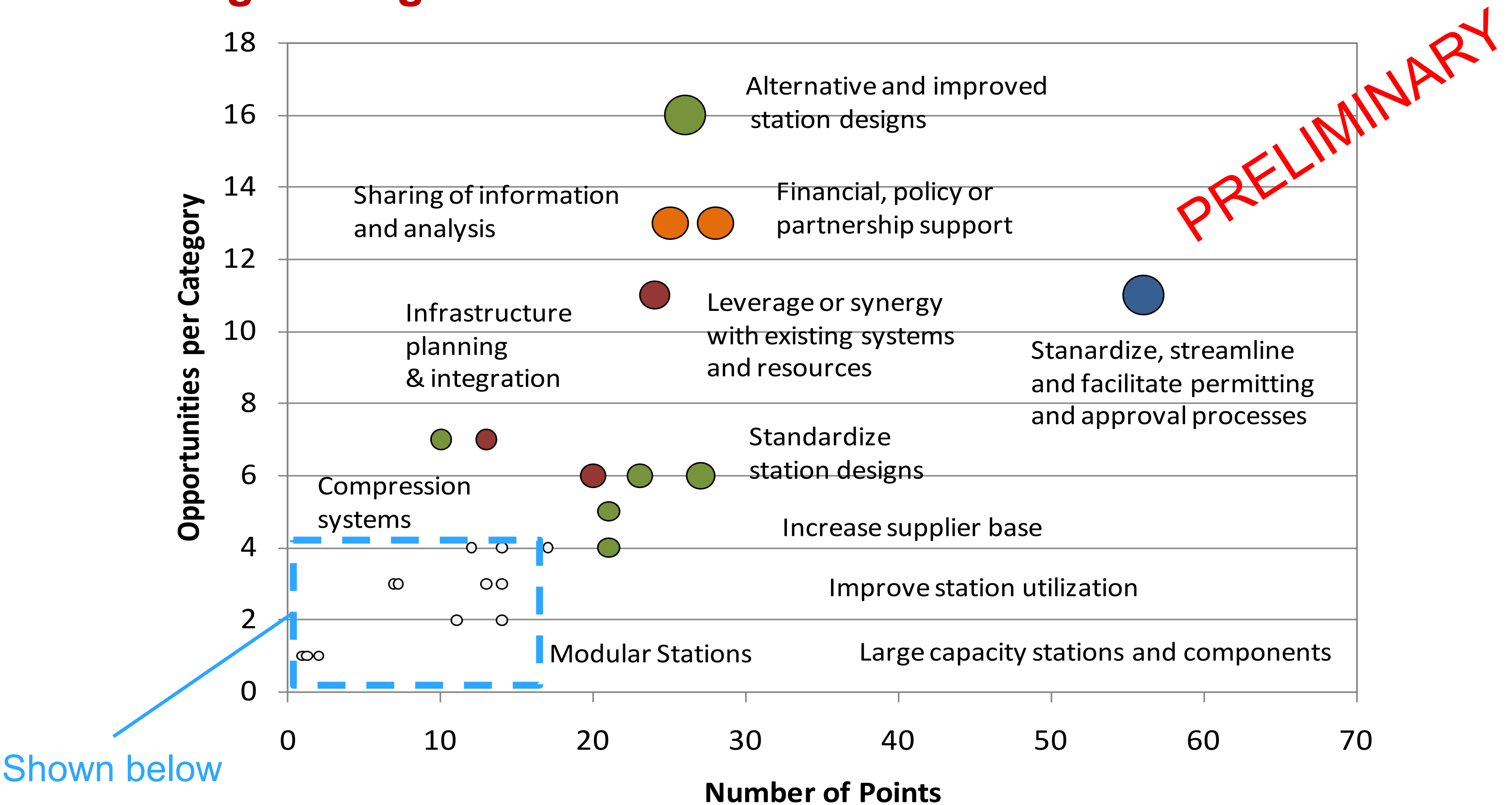
- Low level: opportunities categorized into 24 groups
- High level: opportunities categorized into 4 groups

High level aggregation of opportunities

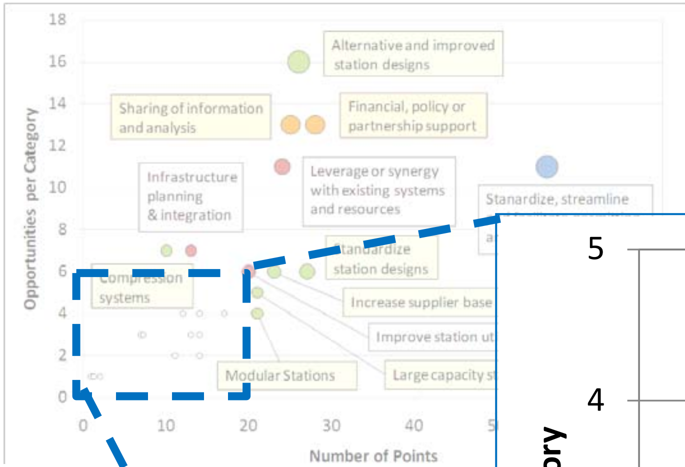


Low level aggregation of opportunities (1)

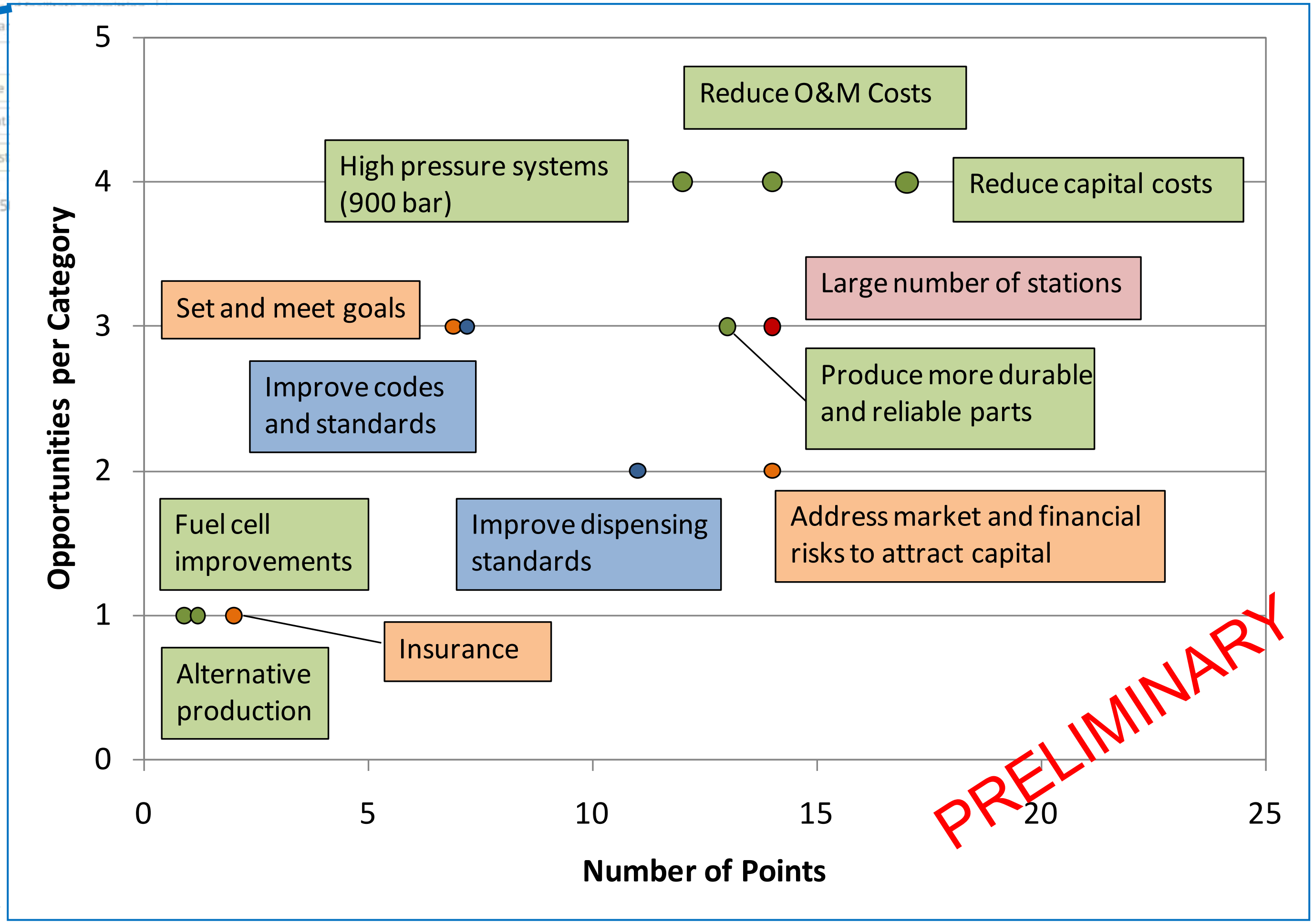
- Approval streamlining opportunities are focused
- Technological opportunities are relatively diverse
- Significant breadth for Institutional, Financial & Policy and Analysis, Planning & Integration



Low level aggregation of opportunities (2)



Groups with fewer opportunities and fewer points



Possible interpretations

Priorities probably represent the expertise and backgrounds of workshop participants

- A different sent of attendees may have emphasized different priorities

Low level aggregation of opportunities may suggest areas for additional discussion or collective action

- Technological sub-groups could be addressed at future workshops
- Different workshop venues or expert groups may be more appropriate for addressing different opportunity topics

RAW FEEDBACK COLLECTED FROM WORKSHOP

Summary of Panel Feedback: Cost Reduction Opportunities

Cost reduction opportunities

- Streamline the standards/permitting process
- Reduce capital equipment costs
- Lower installation and permitting costs
- Reduce land costs
- Lower maintenance costs
- Lower compressor costs
- Bundle demand among different users
- Expand the supply chain
- Increase volume
- Properly match demand and capacity
- Provide scalable station designs
- Produce more durable parts (e.g., O-rings, HIP valves)
- Reduce variability of site preparation, and permitting and installation costs
- Reduce the cost of electrical requirements (for 480 v access)

Summary of Panel Feedback: Actions to Achieve Cost Reductions (1)

Actions to achieve the cost reduction opportunities

- Leverage existing infrastructure (from other applications)
- Continue government funding, especially government cost sharing
- Familiarize fire marshals/local officials with the technology and codes (e.g., develop a package of information with references to codes and targeted presentations)
- Coordinate fire marshals from different localities
- Develop a way for code officials to easily determine what setback distance (or other key parameter) is needed
- Continue DOE workshops for first responders and code officials
- Use economies of scale
- Provide mobile filling stations with no fixed equipment to bring down costs for smaller stations
- Obtain letters from EPA and/or DHS approving the use of hydrogen technology in “critical infrastructure” applications

Summary of Panel Feedback: Actions to Achieve Cost Reductions (2)

Actions to achieve the cost reduction opportunities

- Educate the public
  - Provide open forums with experts
  - Conduct technology showcases
- Provide incentives for individual station owners or dealers
- Develop standard, specific requirements for components (e.g., compressors) that manufacturers can understand and address
- Conduct planning to develop clustered station rollout strategies
- Demonstrate that high throughput stations can be cost effective
- Provide natural gas pipeline accessibility to reduce onsite equipment needs
- Show that fuel cells provide clean, reliable backup power at tens of thousands of cell tower sites to convince other users of backup power (e.g., hospitals) to adopt the technology

Feedback on Priority Opportunities to Reduce Costs (1)

System Station Costs (Design, Performance Requirements)

- Eliminate station design/installation requirements that suffer from overly conservative requirements (e.g., use of fire eyes)
- Increase the number of station components and equipment that have achieved third-party certification for use in H2 service
  - Target processes and components that cause station reliability problems (e.g., O-rings, IR nozzles, HIP valves, etc.)
- Encourage modular station designs that harmonize requirements for small/medium/large stations and enable modular station expansion
- Provide awards for networks of stations using same or similar design rather than one-off projects
- Harmonize/standardize dispensing equipment specs
- Increase the number of suppliers of hydrogen station components and systems

Feedback on Priority Opportunities to Reduce Costs (2)

Component-Level Costs

- Reduce capital equipment costs, especially for high-pressure equipment
- Reduce hydrogen storage costs (e.g., enable use of 14,000 psi storage; composite tanks)
- Reduce compressor capital, operating, and maintenance costs
- Reduce dispensing costs

Breakout Group Results: Summary

Feedback on Priority Opportunities to Reduce Costs (3)

Planning and Permitting (Siting, Cost of Compliance)

- Institute a “type approval” approach for H2 stations to simplify and streamline the permitting process
- Develop a model(s) for a streamlined, uniform permitting process (written for permitting officials)
- Develop targeted, “plain language” information products and forums to educate fire marshals, permitting officials, municipal officials, public, and insurance industry on hydrogen stations

Business Operations / Other

- Increase station volume (increase synergy with multiple markets)
- Sacrifice the number of stations for larger, fully utilized stations
- Provide common data collection and reporting to aid learning

What Are The Biggest Opportunities To Reduce The Costs Of Hydrogen Fueling Stations Over The Next 2–5 Years? (GROUP 1)

Voting Criteria: Which of these represents the LARGEST OPPORTUNITY to reduce the cost of hydrogen fueling stations of the next 2–5 years?

Component-Level Costs (cost to produce)	System Station Costs (design, performance requirements)	Planning and Permitting (siting, cost of compliance)	Business Operations (station utilization/ revenue, investment, finance, coordination, etc.)	Policy	Best Practices
• Design, develop, validate, and manufacture for high-volume production (50 kg) to reduce capital and O&M costs ●	• No more science experiments (In favor of standardized commercial products) ●●●●	• Small setbacks: engineer systems to be safer with a small footprint; underground? ●●	• Expand the supply chain to include volume-minded suppliers versus project-oriented suppliers	• Tax credits for renewable H2 to level the playing field with alternative fuels with NO renewables requirement; reduce capital costs (e.g., cost of electricity) through supportive government legislation, renewable tax credits, etc. ●●●●	• Cost reduction/ learning by doing: Capture all of the learnings from the existing station installations; don't repeat the same problems ●
• Use a modular approach to building stations (small/medium/large) ●●●●●●●●●●●	• Liquid-large stations: delivery, storage; gas dispensing—lower compressor cost, distribution cost, and public anxiety ●●●	• Certify high-pressure storage (ASTM, DOT, CHP) ~14,000 psi	• Increasing the number of stations matures the supply chain and reduces costs of capital equipment ●	• Be willing to sacrifice the number of stations to obtain larger stations, even early on ●●●●●●	• Use a "target-costing" process; 50%–60% reduction goal; set practical targets under the business case, both short and long terms ●●
• Develop more replicates (Follow a Starbucks/ McDonalds model)	• On-site liquefaction with pumping to replace compressor and power requirements (storage/ dispensing)	• Increase H2 safety knowledge of experts; reduce redundant safety factors/footprint	• Increase H2 throughput; Corollary: Guarantee a minimum throughput for deployed stations ●●●	• Demonstrate value to drive demand; cars/ applications, fuel costs, efficiency	• Worldwide benchmarks/ best practices ●●

What Are The Biggest Opportunities To Reduce The Costs Of Hydrogen Fueling Stations Over The Next 2–5 Years? (GROUP 1)

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Component-Level Costs (cost to produce)	System Station Costs (design, performance requirements)	Planning and Permitting (siting, cost of compliance)	Business Operations (station utilization/ revenue, investment, finance, coordination, etc.)	Policy	Best Practices
• Re-evaluate the 3.3x safety factor on composite cylinders used for delivery●●	• Model CO_2 & H_2 energy use (well-to-wheels) of various distribution models and better distribute the information	• Educate fire marshals and municipalities to ease permitting process ●●●●●●●●	• Liquid H2 transfer: Understand/improve to reduce clearance and effort	• Provide awards for a network of stations rather than one-off projects ●●●●●●●●●	
• Cost of 70 MPA hoses (# of suppliers)/ More component manufacturers, a la DoD ●●●●●●		• Type approval approach—once you're approved to install the station, able to install anywhere, to reduce the administrative costs; streamline codes and standards and permitting ●●●●●●●●●●●●●●	• Add more stations to existing H2 pipelines (e.g., Torrance) ●●●●	• DOE or FERC or DOS standards to overrule NFPA/ASME and local fire marshals ●●	
• On-site storage (underground systems, high-volume storage) ●				• Address conflicts with local building requirements/ codes and H2 safety codes ●	
• 900 bar storage cost reduction/ more suppliers ●				• Grid Management; tie to H2	

What Are The Biggest Opportunities To Reduce The Costs Of Hydrogen Fueling Stations Over The Next 2–5 Years? (GROUP 1)

Voting Criteria: Which of these represents the LARGEST OPPORTUNITY to reduce the cost of hydrogen fueling stations of the next 2–5 years?

Component-Level Costs (cost to produce)	System Station Costs (design, performance requirements)	Planning and Permitting (siting, cost of compliance)	Business Operations (station utilization/ revenue, investment, finance, coordination, etc.)	Policy	Best Practices
• Forecourt distribution model (similar to gasoline stations) ●●				• Commitment by Government to support H2 in the long term ●●●●●	
• Support new concepts for compressing at the IS and electrolyzer ●				• 3rd-party reinforcement of H2 policy for mobility	
• Increase vendor base for station construction and operation ●●●					

What Are The Biggest Opportunities To Reduce The Costs Of Hydrogen Fueling Stations Over The Next 2–5 Years? (GROUP 2)

Voting Criteria: Which of these represents the LARGEST OPPORTUNITY to reduce the cost of hydrogen fueling stations of the next 2–5 years?

Component-Level Costs (cost to produce)	System Station Costs (design, performance requirements)	Planning and Permitting (siting, cost of compliance)	Business Operations (station utilization/ revenue, investment, finance, coordination, etc.)	Other
• Large-scale compression ●●●●●● • High-pressure hydrogen storage—14,000 psi ●●●● • Compression for renewables (from 1 psi) ● • Compressor cost and reliability (eliminate need for redundancy) ● • Expand supply chain ● • Station components (O-rings, valves, etc.) • Pursue other methods of pre-cooling	• Reduce capital equipment costs, especially for high pressure ●●●●● • High-pressure hydrogen delivery—14,000 psi ●●● • Station design (especially dispenser) optimized for low cost ●● • Need to reduce station footprint ●● • Standardized designs to support series production of stations (EOS) learn break points ● • HFC TCI must reach diesel ? parity ● • Low-cost station design for low-utilized stations (destination) • Need to increase volume—economy of size	• Dispensing standards optimization ●●●●●●● • Need for more uniform permitting process (un-informed permitting officials) ●●●●●● • Station scaling adaption to growth ●● • Roaming mobile re-fuelers to provide backup supply/refueling ● • Need to revisit codes—issues of interpretation ● • Locate equipment underground • Lower install $ market coordination (area help) • Cost of rooftop installations	• Need to address market risk and attract private capital ●●●●●●● • Capital utilization cost spread over too few kgs; risk not attracting investment ●●●● • Development entity that can use both financial and other assets to offset capital and O&M ●●● • Permit $ market coordination ●● • Need for other financial ROI models • Need to give business consistent long-term message • Cost of capital—rates too high, period too short, methods to improve • Match daily demand to station "status" or availability • Mobile refueling	• Need for shared information ●●●● • Opportunity for coordination and convergence on a single storage process (vehicle) ●●●● • Economic impact analysis of H2 cost parity with gasoline ● • Need for stricter environmental policies/ regulations ● • Station location optimized

What Are The Biggest Opportunities To Reduce The Costs Of Hydrogen Fueling Stations Over The Next 2–5 Years? (GROUP 3)

Voting Criteria: Which of these represents the LARGEST OPPORTUNITY to reduce the cost of hydrogen fueling stations of the next 2–5 years?

Component-level costs (cost to produce)

- Get more suppliers into the market supply chain; access to multiple suppliers ●●●●●
- Station compressor costs: capital (tied to reliability and need for redundancy)
- Operating/Maintenance (ties to not ?, e.g., cost, but station downtime) ●●●●●
- Reduce cost of H2 storage, (e.g., utilization of composite tank storage) ●●●●
- New, improved core technology fuel cells
- Compressor (H35) overhaul costs ~$40K)
- Low-life-cycle cost compression technology, (e.g., electrochemical)
- Ionic liquid compressors

System Station Costs (design, performance requirements)

- Standardize station designs (where possible across applications) and don't "gold plate" it ●●●●●●●●●●
- Target processes and components (e.g., O-rings) that cause station reliability problems for improvement ●●●●●●●●
- Optimize forecourt design with scale-up in mind ●●
- Better match supply and demand (from multiple sources) to reduce redundancy and storage at stations ●●
- O&M expenses reducing labor associated with maintenance ●
- Identify less rigorous design (overly conservative) specifications (step below "gold" standard
- Design/information-sharing database for federal/state funding
- Utilize excess H2 from CHHP
- Siting electrical requirements and system design
- Develop "portfolio" of H2 delivery solution

Planning and Permitting (siting, cost of compliance)

- Better educate officials and public on codes and standards. Standardize information directed at local fire marshal ●●●●●
- Providing 3rd-party certification of equipment ●●●●
- Smart network growth ●
- "Scale economics" in permitting, build on learnings network of experts
- Planning and permitting "fast track" permit process for H2 stations; like SC AQMD does for FC BUP

Business Operations (station utilization/revenue, investment, finance, coordination, etc.)

- Overlap early markets with 2015 auto markets. Find synergy for stations. Government help for reserve capacity ●●●
- Load up the infrastructure with multiple apps (e.g., ?vehicles and MHE and buses) ●●
- Liability insurance ($50K/yr) costs too much ●
- Cost to get government financial help (too high)
- Leverage hydrogen supplies that aren't being fully utilized
- Utilize H2 supply from excess H2 capacity (e.g., NASA operations)
- Utilize waste H2 from industrial H2-intensive processes; localized H2 station, lower delivery
- Increased station volume—reduction in amortized costs
- Gas station integration (co-locate with gas stations) ●●●
- Short pipelines for H2 delivery
- Lower fuel costs—increase supply options (delivered cost of H2 is too high)
  - Why do we pay for H2 molecules and input energy costs
- Siting—take land costs out of the equation where possible by using brownfields, EUL at federal sites, etc.
- Partner to reduce land/site costs

Other

- Common data collection and reporting (ala TechVal) ●●●●
- Intensive (high-utilization) demonstrations outside of California (renewables mandate impedes H2 roll out and is a cost barrier) ●●●
- Cooperation among players ●●●
- Reduce cost of "money" to finance stations ●●●
- Government incentives for new applications for hydrogen ●●
- Consistent H2/energy vision for the United States ●
- Transparent cost analysis from historic programs (data is fuzzy regarding pricing)
- Adopt a collective responsibility to bring H2 to market
- Government challenges/awards regarding feasibility
- Motivation of political will to "win the future" (clear government commitment and carbon policy)
- Include H2 infrastructure (and PHEV) in administrations "infrastructure fund" (road, bridges) proposal
- Develop an updated H2/fuel cell roadmap

Hydrogen Infrastructure Market Readiness Workshop (Group 1)

What can we DO to achieve these high-priority opportunities to reduce hydrogen station costs?

	Economics of Scale/Learning by Doing	R&D	Installation & Permitting	Collaborative Actions	Other
Type Approval Approach; Standardize Process for Permitting; Codes and Standards/ Educate Fire Marshals and Municipalities	• Labor costs dealing with permitting would drop by an order of magnitude if process is standardized, accepted across the country, and shortened to 1/10 the time; also recommended that labor costs could be reduced from 20% to 8%; time from 18 months to 1 month, or from 1 year to 1.5 months; and total costs by 3%–5%	• Clear understanding of each state's permitting requirements; **Action:** database or other information repository; **How:** Coordinate with state fire marshals; **Who:** DOE or Federal partnerships • W-T-E for renewable H2, CNG, electricity; **Who:** DOE • Safety research, flaws proposition; gather, summarize, and distribute correctly interpreted H2 information; Develop and deliver educational campaign for fire marshals and permitting officials **Who:** DOE, Trade associations • Fire marshal testing grounds; **Who:** AQMD in CA, training grounds in HI, DOE (?) • Worldwide standard and disseminated information sharing; **Who:** IPHE (emulate international standards for use in the United States) • Standardize risk management (safety, financial, insurance); **Who:** Central body • Federal funding for component and equipment certification	• At a state level, develop an approved, streamlined permitting process • Agree on reduced setback distances as code improvement (Rely on science-based data for support); **How:** modeling • Develop a codes and standards "swat team" for education and training; use as H2 proponents; **Who:** Federal central body, or collaboration by cities • Open a federal office to help companies in facilitating and permitting	• Share the timeline of implementation of hydrogen/ codes and standard of stations	• Include H2 training in standard U.S. Fire Department training; **Who:** FCF (?) • Continue current codes and standards online courses (keep updating) **Who**: NREL

Hydrogen Infrastructure Market Readiness Workshop (Group 1)
What can we DO to achieve these high-priority opportunities to reduce hydrogen station costs?

	Economics of Scale/Learning by Doing	R&D	Installation & Permitting	Collaborative Actions	Other
Use Modular Approach (Harmonize Requirements); small/medium/large (complete system, design, determined by manufacturer)	• Cut O&M costs for equipment by 75% through using validated components • Modular approach allows for standardized manufacturing, which can lead to significant cost reductions (as much as 50%)	• Fund R&D for high-volume, high-reliability H2 compressor development • Lower compression costs through new technology, electrochemical pump synergistic with PENFC; **Who:** DOE, industry • Cylinder performance evaluation; storage evaluation; HP part testing and evaluation • Fund development of component requirement/ test program • Ensure end-of-life costs are included in analysis: longevity of materials; scaling requirements; fundamentals	• DOE funding of new stations; develop a roll out plan		• Funding from agencies and supportive policies
Provide Awards for Networks of Stations Rather Than One-Off Projects	• Yes; (consensus was that this could be helpful, but the group did not come to a consensus regarding what actions should be taken)		• DOE funding for new stations • Creative ways to reduce capital carrying costs, from 20% to 5% • Evaluation of previous awards for H2 stations	• Collaborate among states to provide awards	• Value capacity, not just $/kg sold
Increase Number of Suppliers	• 5%–6% capital equity cost reduction for doubling the volume of manufacturers, keeping existing technology	• DOE testing of 700 bar components for hoses and materials leading to new ideas for the design of materials		• Detailed station and deployment plan: include all OEMs, focused markets, potentially contractual, provides a 5–10 year outlook	Federal support for suppliers of components

Hydrogen Infrastructure Market Readiness Workshop (Group 1)
What can we DO to achieve these high-priority opportunities to reduce hydrogen station costs?

	Economics of Scale/Learning by Doing	R&D	Installation & Permitting	Collaborative Actions	Other
Sacrifice the Number of Stations for Larger Stations, Fully Utilized	• Maybe (participants felt that this warranted further discussion)		• In at least 1 upcoming station solicitation require min. daily capacity of >500 kg/day		

Hydrogen Infrastructure Market Readiness Workshop (Group 2)

What can we DO to achieve these high-priority opportunities to reduce hydrogen station costs?

	Economics of Scale/Learning by Doing	R&D	Installation & Planning	Operations & Maintenance	Collaborative Actions	Policy Actions	Codes and Standards	Other
Capital utilization - cost spread over too few customers risk not attracting investors	• 20%–30%/kg through clusters	• Design modular expansion stations ●●	• Plan for multiple potential users	• Clustering allows focused support (equipment and personnel)	• OEM communications	• Funding criteria; clustering, multi-use ●●	• NA	• Vehicle to stations communication to shift demand in time
High-pressure hydrogen storage 14,000 psi	• 10% of overall station costs up to 40% for component	• Develop codes cost share for development	• AHJ - support training efforts	• Fund program to extend service life ●	• National labs, DOT	• Federal/state local AHS meetings	• ASME, DOT codes followed ●	•
Need for shared information	• 1%–5%, light duty; 20–40% new markets = larger number of locations & lower number of replications	• Set up a universal web-based database	• Expand existing vehicle education/ outreach/ training to other H2 uses. Create typical model or deployment example ●●	• Workforce training of service operators, certification process, community college, train the trainer	• Early market hydrogen users group—webinar series, conferences, briefings to be posted on website, codes and standards database, AMR like exchange of information across industries ●●●	• Consistent long-term policy directions; give a program sufficient time to mature or die ●●●●●●	• Feedback loop from government to industry; what works, what doesn't, or other	• Industry funded "in part" to help self and all

Hydrogen Infrastructure Market Readiness Workshop (Group 2)
What can we DO to achieve these high-priority opportunities to reduce hydrogen station costs?

	Economics of Scale/Learning by Doing	R&D	Installation & Planning	Operations & Maintenance	Collaborative Actions	Policy Actions	Codes and Standards	Other
Reduce capital equipment costs, especially for high-pressure	• 20%–50%; Look for opportunities to eliminate costs through eng./R&D	• Fund large-scale infrastructure roll out ●●●●●	• NA	• Consider O&M during design & development	• State and local stakeholders, industrial participants ●	• NA	• Refer to permitting topic	• Clear fuel outlet (CA)
Need to address market risk and attract private capital	• NA	• Near-term R&D— mfg., component reliability	• Harmonization of installation process (e.g., statewide)	• NA	• Stakeholder agreements and communication	• Long-term roadmaps with policy goals ●	• Streamline testing and certification requirements ●●●	•
Need for more uniform permitting process	• 20%–30% of station costs	• Set up a universal web-based database●●●	• Expand existing website education, outreach and training to early market H2 users; create models and examples, workshops ●	• Workforce training of service operators, certification process, community colleges, train the trainers	• See 4	• NA	• Code body summary (real words, plain English) of C&S; national or state uniform code on permitting ●●●●●	•

Hydrogen Infrastructure Market Readiness Workshop (Group 2)
What can we DO to achieve these high-priority opportunities to reduce hydrogen station costs?

Large Scale Compression	Economies of Scale/learning by doing	R&D	Installation & Planning	Operations & Maintenance	Collaborative Actions	Policy Actions	Codes and Standards	Other
	• Mostly learned by doing—10% of the capital	• DOE program targeted	• NA	• Support demonstration program	• Coordinate ? energy and gas suppliers	• NA	• NA	•
Dispensing standards optimization - standards - protocol- station costs	• 0%	• Develop low-cost cooling system/ dispensing, validate boundary conditions of operation, validate alternative fuel products ●●	• NA	• Study key dispensing cost drivers for operation & maintenance	• Common funding for data study of optimization ●	• NA	• Complete SAE J2601 with optimization ●●●●	• Complete study and standardization of HVAs ●

Hydrogen Infrastructure Market Readiness Workshop (Group 3)
What can we DO to achieve these high-priority opportunities to reduce hydrogen station costs?

- **Provide better education to officials and the public and insurance industry on codes and standards**
  - Continue C&S workshops
  - Target outreach one-on-one meetings with opinion leaders
    - Seminars to NECA, SIGMA, labor
    - Insurers (NAIC), building inspectors, public works divisions
  - Model the outreach done on vehicle HEVs
  - Set up a network of official that could be resource to others
  - Develop technical validation report on station reliability

- **Standardize station designs (and don't "gold plate")**
  - 30%–50% cost reduction through economies of scale
  - Incentivize smaller-scale suppliers to test and verify reliability of designs
    - Accelerate life testing, testing protocols
  - Station buyers design RFPs incentivize a standard design
  - Forklift and OEM work together to develop both station needs and solutions
  - Integration of compression and storage and dispensing
  - Execute SAEJ......filling protocol
  - Identify which components or station design/installation requirements suffer from over design, e.g., "fire eyes" at stations - heat or H2 defector cheaper

- **Increase station volume (Increase synergy with multiple markets)**
  - Incentivize combining fleet operations with public refueling, e.g., at Fed Ex site)
  - RFPs that require that station be publicly available
  - Survey and database of where this makes sense around the country
  - Co-locate H2 dispensers at gas stations
  - R&D into station designs that link nearby applications with one H2 "generator," (e.g., thru short pipelines, tubes, etc.)
  - Conduct H2A level understanding about volume scaling on infrastructure costs
  - Build learning curves on costs of different components to give guidance

Provide common data collection and reporting

HYDROGEN INFRASTRUCTURE MARKET READINESS WORKSHOP (GROUP 3)
WHAT CAN WE DO TO ACHIEVE THESE HIGH-PRIORITY OPPORTUNITIES TO REDUCE HYDROGEN STATION COSTS?

- **Target processes and components that cause station reliability problems, (e.g., O-rings) Work toward making certified equipment for H2 use / provide 3rd-party certification of equipment**
  - O-rings/ball valves, IR nozzles, compressors (O&M), diaphragm (O&M), fire sensors, pressure sensors, check valves on compressors, pressure release valves
  - Get industry players to work together for common certification—task to FCHEA or industry association
  - Provide government funding support to get testing and certification done (suppliers can’t/won’t on their own)
  - Get suppliers (U.S.) together to talk about how to lower costs/ruggedize
  - Potential for cost $50,000–$100,000 reduction in annual cost

- **Get more suppliers into the market**
  - Provide clear design specs that they can respond to
  - Create “challenge” for design/build
  - Provide information on what demand curve looks like (with error bars); more market analysis
  - Target information toward the T-3 suppliers; their pubs, conferences, associations
  - Are there testing needs that are low risk to them

- **Reduce cost of storage (e.g., utilize composite tank storage)**
  - Evaluate ability to use composite tank storage
  - Develop permitting requirements, etc.

Hydrogen Infrastructure Market Readiness Workshop—Group 2 ACTION PLAN

	How	Who	When
Complete SAE J2601 with optimization	• Continue meetings	• SAE members	• 24 months
Create a national or state code standard with plain language	• "mimic" ASHRAE and IEEE code process—consistent, understandable	• Collaborative federal leadership	• 24 months
Fund and execute large-scale infrastructure roll out	• Collaborative planning • Create list of criteria (punch list) • Run assets through development entities • Identify incentives, put in place	• Task force leads • All stakeholders and agencies • Government co-fund	• In parallel with policy direction, ASAP within 12 months
Consistent long-term policy direction	• Develop U.S. state energy policy that includes H2	• Government with industry collaboration	• ASAP—within 12 months

Categorization & prioritization of opportunities (1)

Opportunity Type
Component-Level Costs (cost to produce)
System Station Costs (design, performance requirements)
Planning and Permitting (siting, cost of compliance)
Business Operations (station utilization/ revenue, investment, finance, coordination, etc.)
Other

1	• Type approval approach—once you're approved to install the station, able to install anywhere, to reduce the administrative costs; streamline codes and standards and permitting ●●●●●●●●●●●●●●	15
2	• Educate fire marshals and municipalities to ease permitting process ●●●●●●●●	9
3	• "Scale economics" in permitting, build on learnings network of experts	1
4	• Planning and permitting "fast track" permit process for H2 stations; like SC AQMD does for FC BUP	1
5	• Providing 3rd-party certification of equipment ●●●●	5
6	• Need for more uniform permitting process (un-informed permitting officials) ●●●●●●	7
7	• Better educate officials and public on codes and standards. Standardize information directed at local fire marshal ●●●●●	6
8	• Streamline the standards/permitting process	3
9	• Lower installation and permitting costs	3
10	• Reduce variability of site preparation, and permitting and installa	3
11	• DOE or FERC or DOS standards to overrule NFPA/ASME and local fire marshals ●●	3
12	• Use a modular approach to building stations (small/medium/large) ●●●●●●●●●●●	12
13	• Station scaling adaption to growth ●●	3
14	• Provide scalable station designs	3
15	• Optimize forecourt design with scale-up in mind ●●	3
16	• Standardize station designs (where possible across applications) and don't "gold plate" it ●●●●●●●●●●	11
17	• Opportunity for coordination and convergence on a single storage process (vehicle) ●●●●	5
18	• Develop more replicates (Follow a Starbucks/ McDonalds model)	1
19	• No more science experiments (In favor of standardized commercial products) ●●●●	5
20	• Standardized designs to support series production of stations (EOS) learn break points ●	2
21	• Standardization of design, improves C&S and suppliers	3
22	• Reduce the cost of electrical requirements (for 480 v access)	3
23	• On-site storage (underground systems, high-volume storage) ●	2
24	• Forecourt distribution model (similar to gasoline stations) ●●	3
25	• Pursue other methods of pre-cooling	1

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Other

26	• Cost of rooftop installations	1
27	• Locate equipment underground	1
28	• Liquid H2 transfer: Understand/improve to reduce clearance and effort	1
29	• Mobile refueling	1
30	• Short pipelines for H2 delivery	1
31	• Siting electrical requirements and system design	1
32	• Utilize excess H2 from CHHP	1
33	• Identify less rigorous design (overly conservative) specifications (step below "gold" standard	1
34	• Low-cost station design for low-utilized stations (destination)	1
35	• On-site liquefaction with pumping to replace compressor and power requirements (storage/ dispensing)	1
36	• Need to reduce station footprint ●●	3
37	• Liquid-large stations: delivery, storage; gas dispensing—lower compressor cost, distribution cost, and public anxiety ●●●	4
38	• Provide awards for a network of stations rather than one-off projects ●●●●●●●●●	10
39	• Design, develop, validate, and manufacture for high-volume production (50 kg) to reduce capital and O&M costs ●	2
40	• Increasing the number of stations matures the supply chain and reduces costs of capital equipment ●	2
41	• Dispensing standards optimization ●●●●●●●	8
42	• Station design (especially dispenser) optimized for low cost ●●	3
43	• Need to address market risk and attract private capital ●●●●●●●	8
44	• Commitment by Government to support H2 in the long term ●●●●●	6
45	• Cost of 70 MPA hoses (# of suppliers)/ More component manufacturers, a la DoD ●●●●●●	7
46	• Increase vendor base for station construction and operation ●●●	4
47	• Expand the supply chain to include volume-minded suppliers versus project-oriented suppliers	1
48	• Get more suppliers into the market supply chain; access to multiple suppliers ●●●●●	6
49	• Expand supply chain ●	2
50	• Expand the supply chain	3

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Other

51	• Large-scale compression ●●●●●●	7
52	• Small setbacks: engineer systems to be safer with a small footprint; underground? ●●	3
53	• Need to increase volume— economy of size	1
54	• Be willing to sacrifice the number of stations to obtain larger stations, even early on ●●●●●●	7
55	• Increase volume	3
56	• Operating/Maintenance (ties to not ?, e.g., cost, but station downtime) ●●●●●	6
57	• O&M expenses reducing labor associated with maintenance ●	2
58	• Lower O&M costs	3
59	• Reduce land costs	3
60	• Produce more durable parts (e.g., O-rings, HIP valves)	3
61	• Station components (O-rings, valves, etc.)	1
62	• Target processes and components (e.g., O-rings) that cause station reliability problems for improvement ●●●●●●●●	9
63	• Reduce capital equipment costs, especially for high pressure ●●●●●	6
64	• Reduce cost of H2 storage, (e.g., utilization of composite tank storage) ●●●●	5
65	• Lower compressor costs	3
66	• Reduce capital equipment costs	3
67	• High-pressure hydrogen storage—14,000 psi ●●●●	5
68	• High-pressure hydrogen delivery—14,000 psi ●●●	4
69	• Certify high-pressure storage (ASTM, DOT, CHP) ~14,000 psi	1
70	• 900 bar storage cost reduction/ more suppliers ●	2
71	• Smart network growth ●	2
72	• Cooperation among players ●●●	4
73	• Develop "portfolio" of H2 delivery solution	1
74	• Properly match demand and capacity, through planning	3
75	• Match daily demand to station "status" or availability	1

Categorization & prioritization of opportunities (1)

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Other

76	• Lower installation costs through market coordination (area help)	1
77	• Station location optimized	1
78	• Grid Management; tie to H2	1
79	• Utilize waste H2 from industrial H2-intensive processes; localized H2 station, lower delivery	1
80	• Gas station integration (co-locate with gas stations) ???	4
81	• Utilize H2 supply from excess H2 capacity (e.g., NASA operations)	1
82	• Leverage hydrogen supplies that aren't being fully utilized	1
83	• Overlap early markets with 2015 auto markets. Find synergy for stations. Government help for reserve capacity ???	4
84	• Add more stations to existing H2 pipelines (e.g., Torrance) ????	5
85	• Siting—take land costs out of the equation where possible by using brownfields, EUL at federal sites, etc.	1
86	• Partner to reduce land/site costs	1
87	• Roaming mobile re-fuelers to provide backup supply/refueling ?	2
88	• Bundle demand among different users	3
89	• Use a "target-costing" process; 50%–60% reduction goal; set practical targets under the business case, both short and long terms ??	3
90	• HFC TCI must reach diesel ? parity ?	2
91	• Economic impact analysis of H2 cost parity with gasoline ?	2
92	• Capital utilization cost spread over too few kgs; risk not attracting investment ????	5
93	• Intensive (high-utilization) demonstrations outside of California (renewables mandate impedes H2 roll out and is a cost barrier) ???	4
94	• Load up the infrastructure with multiple apps (e.g., ?vehicles and MHE and buses) ??	3
95		
96	• Increased station volume—reduction in amortized costs	1
97	• Better match supply and demand (from multiple sources) to reduce redundancy and storage at stations ??	3
98	• Increase H2 throughput; Corollary: Guarantee a minimum throughput for deployed stations ???	4
99	• Need for shared information ????	5
100	• Worldwide benchmarks/ best practices ??	3

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Other

101	• Consistent H2/energy vision for the United States ●	2
102	• Demonstrate value to drive demand; cars/ applications, fuel costs, efficiency	1
103	• Transparent cost analysis from historic programs (data is fuzzy regarding pricing)	1
104	• Develop an updated H2/fuel cell roadmap	1
105	• Need to give business consistent long-term message	1
106	• Increase H2 safety knowledge of experts; reduce redundant safety factors/footprint	1
107	• Need for other financial ROI models	1
108	• Design/information-sharing database for federal/state funding	1
109	• Model CO2 & H2 energy use (well-to-wheels) of various distribution models and better distribute the information	1
110	• Cost reduction/ learning by doing: Capture all of the learnings from the existing station installations; don't repeat the same problems ●	2
111	• Common data collection and reporting (ala TechVal) ●●●●	5
112	• Tax credits for renewable H2 to level the playing field with alternative fuels with NO renewables requirement; reduce capital costs (e.g., cost of electricity) through supportive government legislation, renewable tax credits, etc. ●●●●	5
113	• Development entity that can use both financial and other assets to offset capital and O&M ●●●	4
114	• Permit $ market coordination ●●	3
115	• Cost to get government financial help (too high)	1
116	• Include H2 infrastructure (and PHEV) in administrations "infrastructure fund" (road, bridges) proposal	1
117	• Motivation of political will to "win the future" (clear government commitment and carbon policy)	1
118	• Government challenges/awards regarding feasibility	1
119	• Adopt a collective responsibility to bring H2 to market	1
120	• 3rd-party reinforcement of H2 policy for mobility	1
121	• Need for stricter environmental policies/ regulations ●	2
122	• Government incentives for new applications for hydrogen ●●	3
123	• Cost of capital—rates too high, period too short, methods to improve	1
124	• Reduce cost of "money" to finance stations ●●●	4
125	• Re-evaluate the 3.3x safety factor on composite cylinders used for delivery●●	3

Categorization & prioritization of opportunities (1)

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Other

126	• Need to revisit codes— issues of interpretation ●	2
127	• Address conflicts with local building requirements/ codes and H2 safety	2
128	• Support new concepts for compressing at the IS and electrolyzer ●	2
129	• Compression for renewables (from 1 psi) ●	2
130	• Compressor cost and reliability (eliminate need for redundancy) ●	2
131	• Station compressor costs: capital (tied to reliability and need for redundancy)	1
132	• Compressor (H35) overhaul costs ~$40K)	1
133	• Low-life-cycle cost compression technology, (e.g., electrochemical)	1
134	• Ionic liquid compressors	1
135	• Liability insurance ($50K/yr) costs too much ●	2
136	• New, improved core technology fuel cells	1
137	• Lower fuel costs—increase supply options (delivered cost of H2 is too high)	1

Thank You!

Please send comments to:
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