NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Analysis of Storage Needs for Early Motive Fuel Cell Markets

2011 DOE Annual Merit Review

Jennifer Kurtz

5/13/2011

Project ID: ST097

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

Project Start Date: October 2010

Project End Date: September 2011

Percent Complete: 40%

Barriers

Lack of knowledge of energy storage performance needs for early fuel cell motive markets.

Budget

Total Project Funding

DOE share: $300k

Contractor share: $0

Funding Received in FY10: $0k

Funding Received in FY11: $300k

Partners

Sandia National Laboratory

- Storage Needs in non-motive markets
- Lennie Klebanoff

Pacific Northwest National Laboratory

- Technology and Manufacturing Readiness Level Analysis
- Ewa Ronnebro

Objectives - Relevance

Identify needs for onboard hydrogen storage and gaps of current hydrogen storage technologies to these needs in early fuel cell motive markets; providing information to focus R&D efforts in hydrogen storage technologies that can accelerate market adoption.

Markets

- Target key early fuel cell motive markets like material handling equipment, ground support equipment, public transit, and unmanned vehicles.

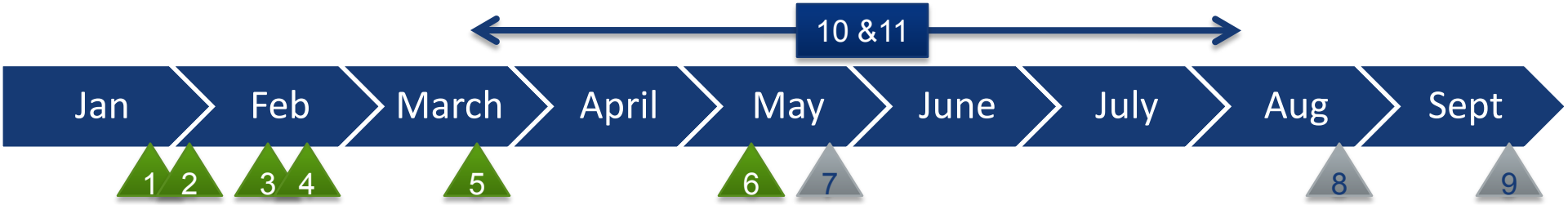
Needs

- Work with end users in the key markets to understand the performance needs related to onboard energy storage.

Gaps

- Work with hydrogen storage experts and manufacturers to understand current technology capabilities and how that compares with the market performance needs.

Milestones – Approach and Accomplishments



1. Workshop plans and questionnaires developed
2. Webinar with hydrogen metal hydride experts
3. Organized “Onboard Energy Storage Performance Needs for Fuel Cell Motive Markets” workshop held in conjunction with FCHEA conference
4. Participated in “Utilizing Hydrogen Power as an Alternative Energy Source” workshop at the “Military Energy Alternatives” conference
5. Organized “Onboard Energy Storage Performance Needs for Material Handling Equipment” workshop held in conjunction with ProMat2011
6. Annual Merit Review
7. Conduct another motive market workshop March-June 2011: if needed to address gaps in the information gathering for a specific application
8. Complete draft final report for DOE review
9. Submit the final report.
10. Ongoing: results and gap analysis
11. Ongoing: stakeholder contacts

Information Gathering – Approach

Work with end users, manufacturers, and experts to gather information through workshops and questionnaires for an analysis to identify the motive market specific performance needs and current hydrogen storage technology gaps.

Workshops

- Breakout sessions
- Dialog within and across key applications
- Discuss important performance metrics
- Brainstorm, rank, and prioritize performance metrics and capabilities
- Audience experience range from none to expert

Questionnaire

- Focus audience is industry stakeholders and end users
- Based on the Kano Method
- Identification of key performance metrics and quantitative performance needs
- Energy storage technology agnostic

Analysis

- Based on the Kano Method
- Compare multiple hydrogen storage technology capabilities with end user performance needs
- Identify gaps between current capabilities and performance needs

Workshop Plans – Accomplishment

Breakout group focus questions

rning or Afternoon Session

ernoon Session

MORNING SESSION

8:15 **Registration/Check-in and coffee, Room 501 B/C**

8:45 **Workshop Overview**

9:00 **Breakout Discussion Session:**

- **Focus Question 1:** What are the key performance needs for your material handling equipment?
- **Focus Question 2:** How could advanced onboard energy storage technology improve the performance of your vehicles or operations?

11:30 **LUNCH** (provided, for **both** morning and afternoon session participants)

Expert Panel Presentations and Q&A

- *Brian Nowicki, Nuvera Fuel Cells*
- *Eric Jensen, Crown Equipment Corporation*
- *Frank Devlin, The Raymond Corporation*
- *Sanjiv Malhotra. Oorja Protonics*

1:30 **Adjourn**

Panel discussions

Held in conjunction with industry gatherings

Workshop: Onboard Energy Storage Performance Needs for Material Handling Equipment

March 21, 2011
Chicago, Illinois
Free admission, limited number of participants.

National Renewable Energy Laboratory (NREL) of the US Department of Energy

The workshop will

- Convene equipment developers, manufacturers, end users, and expert stakeholders to discuss important performance requirements for material handling equipment, and the impacts these requirements have on onboard energy storage needs.
- Discuss the strengths and weaknesses of current onboard energy storage technologies (i.e., batteries, ultracapacitors, propane, diesel, hydrogen, and methanol) for meeting your material handling performance needs, and identify opportunities for improvement.

Workshop purpose

The information from this workshop (combined with feedback from the **on-line questionnaire** and other workshops) will be used by NREL to identify performance needs and gaps for further research and development of onboard energy storage in fuel cell powered material handling equipment. Public results will be published in the Fall of 2011.

Agenda: Please Register for either the Morning or Afternoon Session

Download the Full Agenda → Morning Session Afternoon Session

MORNING SESSION

8:15 **Registration/Check-in and coffee, Room 501 B/C**

8:45 **Workshop Overview**

9:00 **Breakout Discussion Session:**

- **Focus Question 1:** What are the key performance needs for your material handling equipment?

Workshop Details

- Monday March 21, 2011
- **McCormick Place South, Room 501 B/C** 2301 S. Lake Shore Drive, Chicago, IL
- Convention Center **Map**

2 SESSIONS TO CHOOSE FROM!

1. Morning: 8:45 – 1:30 (including lunch) or
2. Afternoon: 11:30 – 4:30 (including lunch)

Register Here

ONBOARD ENERGY STORAGE QUESTIONNAIRE

Please take a minute to fill out the **on-line Questionnaire!**

QUESTIONS?

Contact Chris Ainscough - **chris.ainscough@nrel.gov**

ORGANIZERS

U.S. DEPARTMENT OF ENERGY
Fuel Cell Technologies Program of the Office of Energy Efficiency and Renewable Energy
NREL

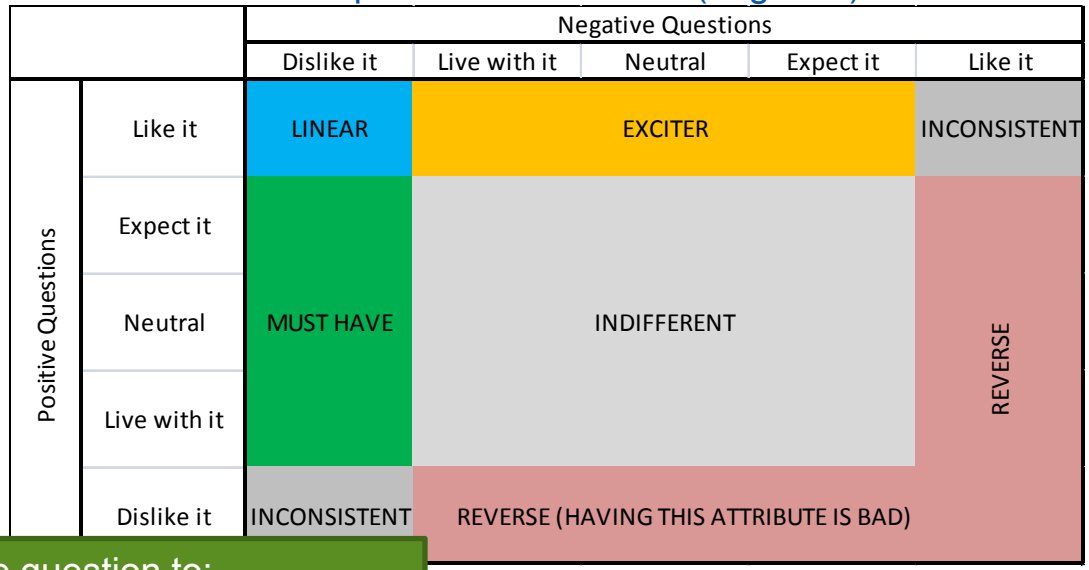
In conjunction with **ProMat® 2011**

Workshop attendance is open to the public. Free registration for ProMat® 2011 is required to attend.

Kano Method - Approach

- Widely used in industry.
- Classifies solution-independent customer needs by:
  - Must have
  - Linear (more is better)
  - Exciter (I can live without that, but it's really cool if I can get it.)
- Questions are asked in positive and negative pairs:
  - "How would you feel if your vehicle could go for an entire shift without fueling?" (positive)
  - "How would you feel if your vehicle had to be fueled multiple times in a shift?" (negative)
- NREL added a third question for each performance category to gather quantitative data.
  - How long is a typical shift?
- Results for each topic are plotted on a positive / negative plane

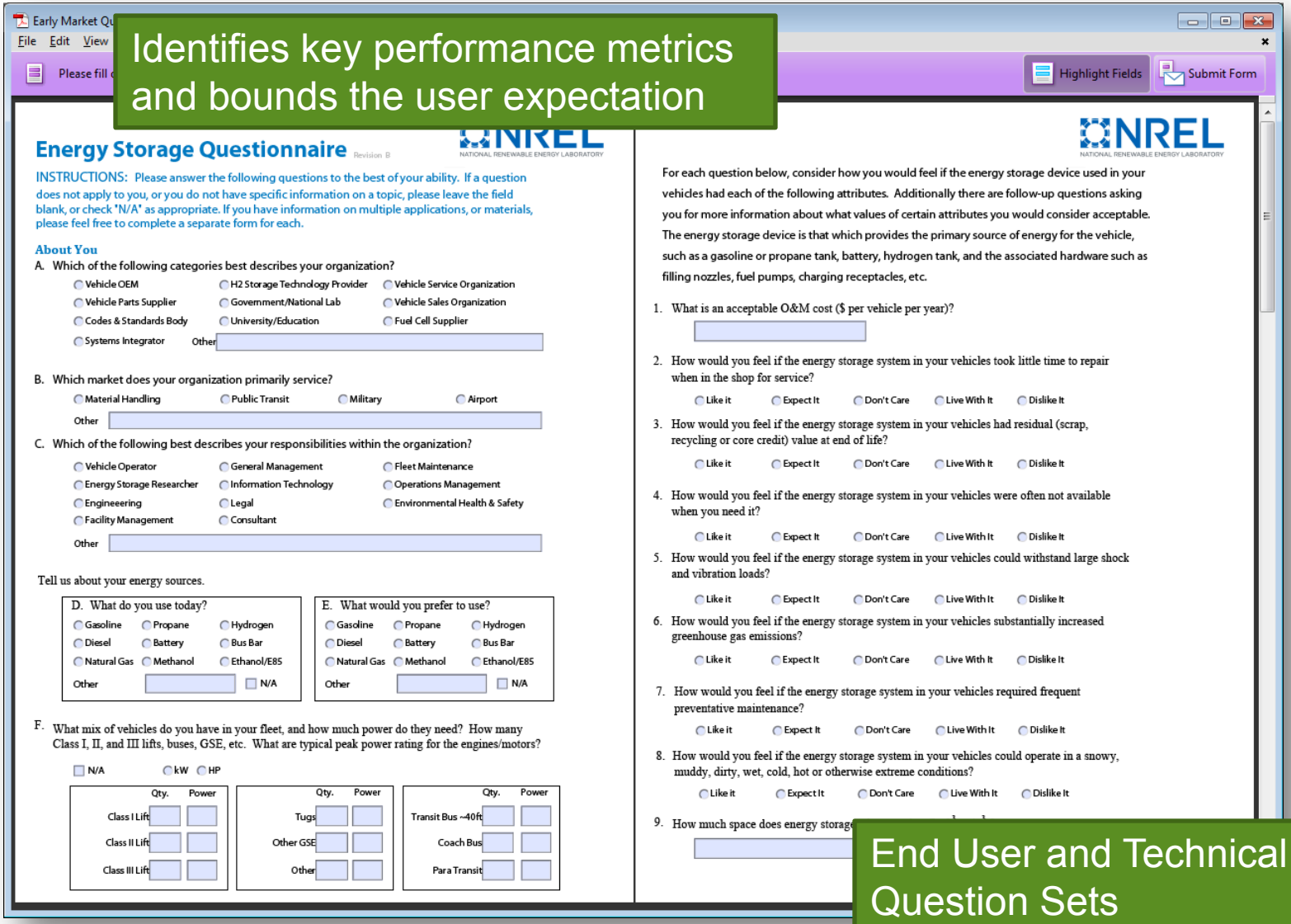
Kano analysis method classifies solution-independent customer needs by importance



Combine the Kano plot with the quantitative question to:

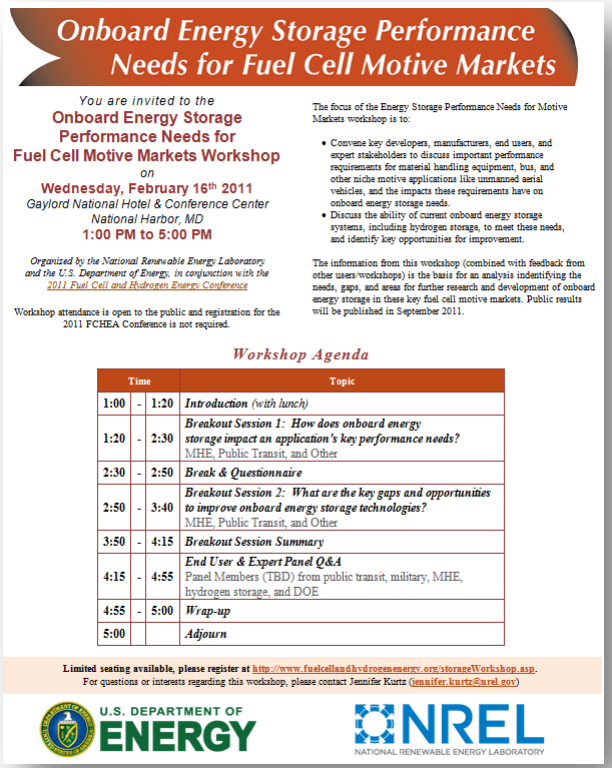
- Identify performance metrics important to the user
- Connect important performance metrics to operation values

Electronic Questionnaire – Accomplishment



February 16th Workshop Data Results Summary – Accomplishment

- 7 Questionnaires received so far
- Two breakout groups from 2/16 workshop – with a facilitator, note taker, and technical advisor
  - Public Transit Bus Breakout Group
    - 12 participants but not many end users
  - Material Handling Breakout Group
    - 16 participants and also including representatives from the unmanned vehicle application
  - Focus questions were the same for both groups
- Workshop materials and questionnaire were sent as follow up to the attendees
- Facilitation report received



Onboard Energy Storage Performance Needs for Fuel Cell Motive Markets

You are invited to the
Onboard Energy Storage Performance Needs for Fuel Cell Motive Markets Workshop
on
Wednesday, February 16th 2011
Gaylord National Hotel & Conference Center
National Harbor, MD
1:00 PM to 5:00 PM

Organized by the National Renewable Energy Laboratory and the U.S. Department of Energy, in conjunction with the 2011 Fuel Cell and Hydrogen Energy Conference

Workshop attendance is open to the public and registration for the 2011 FCHEA Conference is not required.

The focus of the Energy Storage Performance Needs for Motive Markets workshop is to:

- Convene key developers, manufacturers, end users, and expert stakeholders to discuss important performance requirements for material handling equipment, bus, and other niche motive applications like unmanned aerial vehicles, and the impacts these requirements have on onboard energy storage needs.
- Discuss the ability of current onboard energy storage systems, including hydrogen storage, to meet these needs, and identify key opportunities for improvement.

The information from this workshop (combined with feedback from other users/workshops) is the basis for an analysis indentifying the needs, gaps, and areas for further research and development of onboard energy storage in these key fuel cell motive markets. Public results will be published in September 2011.

Workshop Agenda

Time			Topic
1:00	-	1:20	*Introduction (with lunch)*
1:20	-	2:30	*Breakout Session 1: How does onboard energy storage impact an application's key performance needs?* MHE, Public Transit, and Other
2:30	-	2:50	*Break & Questionnaire*
2:50	-	3:40	*Breakout Session 2: What are the key gaps and opportunities to improve onboard energy storage technologies?* MHE, Public Transit, and Other
3:50	-	4:15	*Breakout Session Summary*
4:15	-	4:55	*End User & Expert Panel Q&A* Panel Members (TBD) from public transit, military, MHE, hydrogen storage, and DOE
4:55	-	5:00	*Wrap-up*
5:00			*Adjourn*

Limited seating available, please register at http://www.fuelcellandhydrogenenergy.org/storageWorkshop.asp.
For questions or interests regarding this workshop, please contact Jennifer Kurtz (jennifer.kurtz@nrel.gov)

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Half day workshop held with FCHEA conference, with two breakout groups focused on public transit and material handling with 28 participants.

Breakout Discussion – Group 1 (MHE)
Top Performance Needs Summary – Accomplishment

Need: Robust tanks capable of high cycling over 10 years

- Robustness
  - Industrial environment requires reliable, easy to retrofit or replace and does not require frequent or extensive maintenance
  - Guaranteed lift-span of ~ 10 years for tanks

Need: Certified field support with low maintenance requirements

- Maintenance Costs
  - Maintenance at least equal to preventative maintenance for incumbent technologies (e.g,. 2–3 hours per 500 operation hours)

Need: Onboard storage capacity limits for alternative storage technologies

- Vehicle Runtime
  - One shift (e.g., 8 hours for MHE but 35–40 hours for unmanned vehicles)

Need: Systems specific to hydrogen fuel cell forklifts

- Ease of Use
  - Fill frequency, time, interface, and footprint
- Redundancies
- Ever-increasing power demands

Breakout Discussion Group 2 (Public Transit)
Top Performance Needs Summary – Accomplishment

Need: Reduce cost of storage through consistent tank system design

- Cost of storage
  - The low weight requirement drives the H_2 storage to be carbon fiber, which is very expensive.
  - The storage system is typically designed each time, but repetition in tank system design could help reduce cost.

Need: Low storage system weight

- Weight
  - Fuel cell bus should weigh the same or less than a diesel hybrid bus because of transit agencies weight and size limits as well as potential DOT weight limits
  - Space for the storage may be better optimized to decrease weight.

Need: Operation period to match the bus

- Lifetime
  - Operation lifetime should match that of the bus (12 years/500,000 miles or < 5,000 tank cycles).
  - Current compressed storage technology meets this but alternative technologies may not.
- Range (200–250 miles/day)

Panel Discussion Highlights – Accomplishment

- Successes and challenges with hydrogen fuel cell applications
  - "Hydrogen boogeyman"
  - Unmanned hydrogen fueled airplane with liquid hydrogen
  - Hydrogen fuel cell buses have decreased weight by 6,000 pounds by decreasing unnecessary storage space, but these buses are still too heavy
- Redundancies
  - Are there redundancies that can be eliminated to reduce costs?
  - For example, study the extra layers of carbon fiber that could be reduced if not serving the intended purpose
  - For example, are there components in the design that can be simplified or removed

Summarized breakout discussions and similarities and differences across the applications

Workshop Lessons Learned – Accomplishment

- The external facilitation went well. The facilitators transcribed all of the panel discussion, breakout discussion points, and key needs voting.
- Holding workshops in conjunction with other industry gatherings targets an audience but can also have conflicts with other meetings and events.
- The workshop kickoff presentation can help get the audience energized for the breakout session discussions.
- Audience experience varied from expert in fuel cells and hydrogen to novice user.
- Two breakout sessions worked well and allowed for some flexibility on topic discussion while still focusing in on an application.
- The question of identifying performance needs produced more discussion than the question of what areas can be improved.
- We need more end users involved.

Lessons learned were incorporated into workshop held at ProMat2011

March 21st Workshop Data Results Summary – Accomplishment

- End user focus on MHE applications
- Two half day sessions
  - Same breakout format and same focus questions
  - Facilitator, note taker, and technical advisor
- Panel presentations and discussions (4 industry panel members)
- 22 Attendees
- 11 Questionnaires

Workshop held in conjunction with MHE industry expo (ProMat2011) and focused on MHE end users.

Need: Fast and convenient filling

- Fill/Recharge Time
  - Quick, convenient fueling at 2-3 minutes is very good
  - Fill time and convenience are more important than long continuous run time (~ greater than 5 hours or a shift)

Need: Flexibility in storage design to fit within existing products

- Weight & Volume
  - Most common integration: system treated as a retro-fit and not a new, integrated design
  - Fit in existing battery spaces (weight, center of gravity, and dimensions)
  - Increased fuel cell system weight (~4x)

Need: Simple, low cost options

- Simplicity
  - Simple is necessary to compete with batteries
  - Low cost maintenance requires a simple system that is easy to install, use, and maintain
- Cost
  - Low cost is necessary to compete with batteries

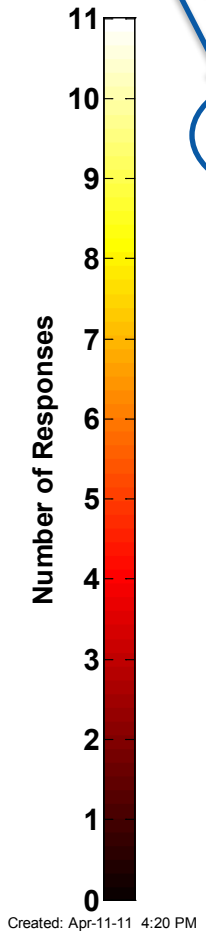
Draft Result With Kano Method – Accomplishment

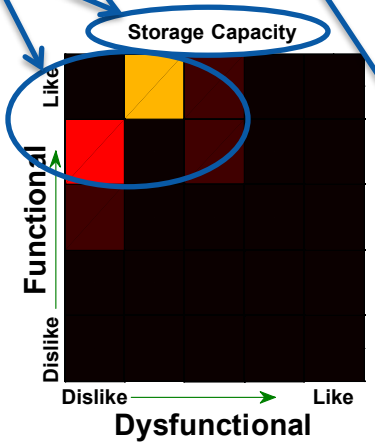
Important Performance Metric

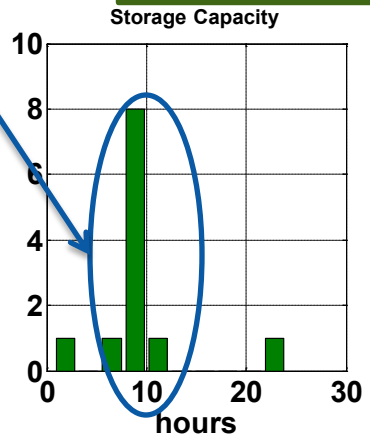
Expect ~ 10 hrs capacity

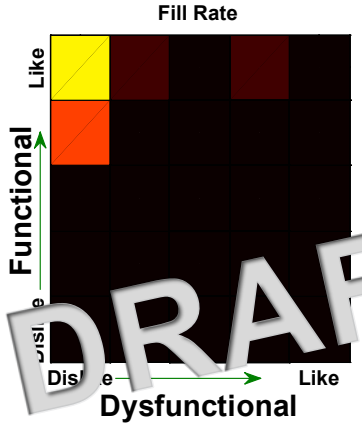
Early draft results of 16 responses including material handling (13), public transit (1), military (1), and other(1).

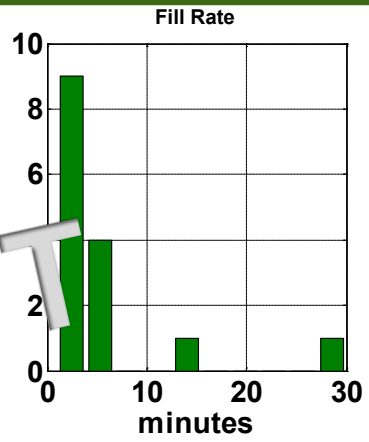
Other topic groups not shown include cost, maintenance, operation environment, physical constraints, and safety.











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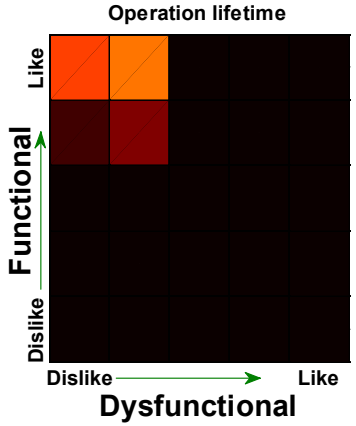

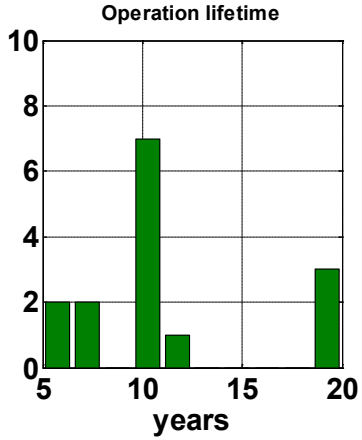

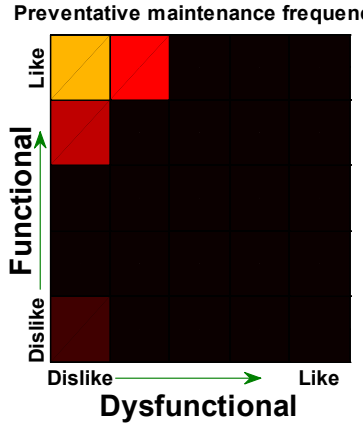

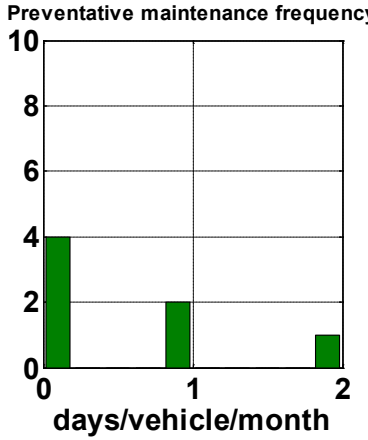

Expect more responses (separated by application and topic group) to be included in final report.

Collaborations

Sandia National Laboratory

- Non-motive markets
- Lennie Klebanoff

Pacific Northwest National Laboratory

- Technology and Manufacturing Readiness Level Analysis
- Ewa Ronnebro

Collaboration activities include:

Co-participation at workshops

SharePoint site

Shared and combined contact lists

Shared questionnaires and analysis methods

Regular teleconferences

Future Work

- Ongoing contact of key stakeholders for questionnaire responses.
- Application specific information gathering (*April – June*)
  - Complete MHE and Bus information gathering (*May*)
  - Focus on other early motive fuel cell markets like unmanned vehicles, military, heavy duty, and ground support equipment (*May - June*)
  - Conduct another motive market workshop (if needed)
  - Review of other industry gatherings and conferences to determine if attendance would be beneficial to project objectives
- Gather technical capabilities of current hydrogen storage technologies (*April – June*)
- Ongoing analysis of questionnaire responses and workshop data (*April – June*)
- Gap analysis of current hydrogen storage technologies to early fuel cell motive market performance needs (July)
- Complete draft final report for DOE review (*August*)
- **Submit the final report addressing onboard storage needs for early fuel cell motive markets and the corresponding hydrogen storage gaps. (*September*) Expected sections are**
  - Key market summaries
  - Application specific performance needs focused on onboard storage
  - Capabilities and gaps for existing hydrogen storage options
  - Potential improvements for hydrogen storage systems.

Summary

- Principal components
  - Early fuel cell motive markets
  - Market performance needs
  - Gaps of current hydrogen storage technology capabilities to the user identified performance needs
- Tools
  - Workshops
  - Questionnaire
  - Kano Analysis Method
- Early results
  - Performance needs are application specific
  - Examples of key performance parameters are robustness, continuous runtime, weight, and cost
- Relevance
  - Project findings will aid DOE in focusing hydrogen storage R&D efforts for early motive fuel cell markets thus supporting DOE's fuel cell market acceleration efforts.

Technical Backup Slides

Key Performance Needs – MHE

Vehicle Fill/Recharging Time	Vehicle Operating Time of Distance Per Fill	Storage System Size & Weight	Vehicle Operating Environment	Things I would Change about Current MHE Performance
Run time of vehicles (8 hrs) ●●●●●	Run time: 30 hrs–60 days, 80 kWh–1800 kWh ● Government sponsored enterprises are application driven and the size of the fuel cell needed to replace a battery is dependent upon the application; in most cases more experience is needed	Gaseous H_2 storage capacity = kg/kW of capacity depending on application; capacity has to meet form factor, 8 hr cut-off ●●●●● Weight of the fuel cell has to be the same as the battery that's being replaced, 900–2600 lbs ●●● Space needed for energy storage - size won't change much (couple more percent), forklift application defines it (overall footprint)	Footprint: equipment on-site, indoor refueler ventilation, and union requirements ●●●●● Robustness: 5–7 days of availability, vehicles treated like a "rental car," military is operational 24/7 ●●●●● Maintenance costs: ○ Forklift, 2 hrs/wk/vehicle, ○ Military truck, 2–3 hrs/300 hrs Ease of use/integration - no retrofitting ●●●● Five-year life for existing fuel cell systems with scheduled maintenance ● Distributed-generation utility infrastructure ● Pollution abatement for advanced emissions ● Thermal management: outside temperature, vibration, temperature swings, and dust factors	Retrofits vs. new products which could improve efficiency and cost ●● Fuel cell systems do not support next generation truck power demand—manufacturers have to increase truck performance; storage systems are not keeping up, 10% growth (15kW) Every fuel cell manufacturer working on this (platinum content, battery competitors), only fuel cells can keep up with demand Customer driven business: customers need to want these products, redundancy is a problem as we are losing efficiencies One to two kW for UUVs, over 200 kW for extenders underwater

•Voting – Which needs present biggest challenges for onboard hydrogen storage to meet

Key Performance Needs – Bus

Vehicle Operating Equipment	Storage System Size and Weight	Vehicle Fill/ Recharging Time	Vehicle Operating Time of Distance per Fill	Costs	Emissions	Capacity	Other
Operate on hills without problems (San Francisco)	Weight: less than or equal to a diesel hybrid bus (weight on the road is limited by DOT regulations and transit agency limits regarding lift equipment) ●●●●●●●●●●	6–10 minute fill time (30 kg in 5-6 mins at 350 Bar); this time frame aligns with related cleaning and other daily maintenance activities ●●	Should be able to travel ~200–250 miles per day ●●●●●	Cost of storage (depends on bulk purchasing) 5 kg tank ~$2,000 ●●●●●●●●●●●	Needs to be able to be certified zero emissions per bus regulations in California	Able to carry 35–37 seated passengers, plus 15 standing passengers (for an inner-city bus) ●●●	Bus lifetime of 12 years or 500,000 miles ●●●●●●
Speed: ≥ 55 mph	Size/ Space: Enough room on the roof for H2 storage system ●●		Once per day filling frequency (same as when buses are cleaned) ●●●●	Purchase Price: Costs need to be on par with the cost of a diesel hybrid (~$750,000); the current cost of an H2 bus is ~$2.2 million ●●●●●●			Maintenance: Must meet maintenance specifications, and be superior to a diesel hybrid ●●

•Voting – Which needs present biggest challenges for onboard hydrogen storage to meet