2015 Hydrogen and Fuel Cells Program Annual Merit Review Meeting

Hydrogen Energy Systems as a Grid Management Tool

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Project: MT008

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Overview

Timeline

- ✓ **Project start date: 30 Sep 10**
- ✓ **Project end date: 29 Sep 15**
- ✓ **Percent complete: 90%**

Barriers

A. Inadequate standards and complex and expensive permitting procedures.

C. Inadequate private sector resources available for infrastructure development.

H. Utilities lack awareness of potential renewable hydrogen storage applications.

Budget

- ✓ **Expended as of 4/15/15: $4,060,000**
- ✓ **Total Project Value : $5,040,000**
- ✓ **Cost Share %: $3,000,000 (60%)**

Partners

- ✓ **US DOE:** Project Sponsor & Funding
- ✓ **NRL:** Federal Technical Program Manager
- ✓ **ONR:** Supplemental funding
- ✓ **HNEI:** Implementing Partner, Technical Lead
- ✓ **State of Hawaii**: Supplemental Funding
- ✓ **Natural Energy Laboratory Hawaii Authority:**
  - ➢ Host site.
- ✓ **County of Hawaii Mass Transit Agency:**
  - ➢ Bus Operator
- ✓ **HCATT:** Bus Conversion & Cost Share
- ✓ **US Hybrid:** Bus Conversion & Cost Share.

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Relevance

Project Objectives

- ✓ **Demonstrate the performance, durability & cost benefits of grid integrated hydrogen systems (Barriers C & H);**
  - ➢ **Operate electrolyzers under dynamic load conditions to mitigate impacts of intermittent renewable energy (Barrier H);**
  - ➢ **Supply hydrogen to shuttle buses operated by County of Hawaii Mass Transit Agency, and Hawaii Volcanoes National Park (Barrier C);**
- ✓ **Support development of regulatory structure for permitting and installation of hydrogen systems in Hawaii (Barrier A).**

This Reporting Period

- ✓ **Developed cycling test protocols based on operational data from 1 MW Battery Energy Storage System installed on HELCO grid for frequency regulation (Barrier H);**
- ✓ **Completed fabrication of Fuel Cell Electric Bus including air filtration system for operation in harsh environment (Barrier A, ONR funding);**
- ✓ **Finalized siting, finalizing permitting, corporate & public acceptance, and Codes & Standards (Barriers A & C).**

Approach: Central Site Production & Leveraged Resources (Barriers A,C,H)

For hydrogen to be accepted in the marketplace it must be economically viable. For electrolytic hydrogen this requires low cost electricity + high capital utilization.

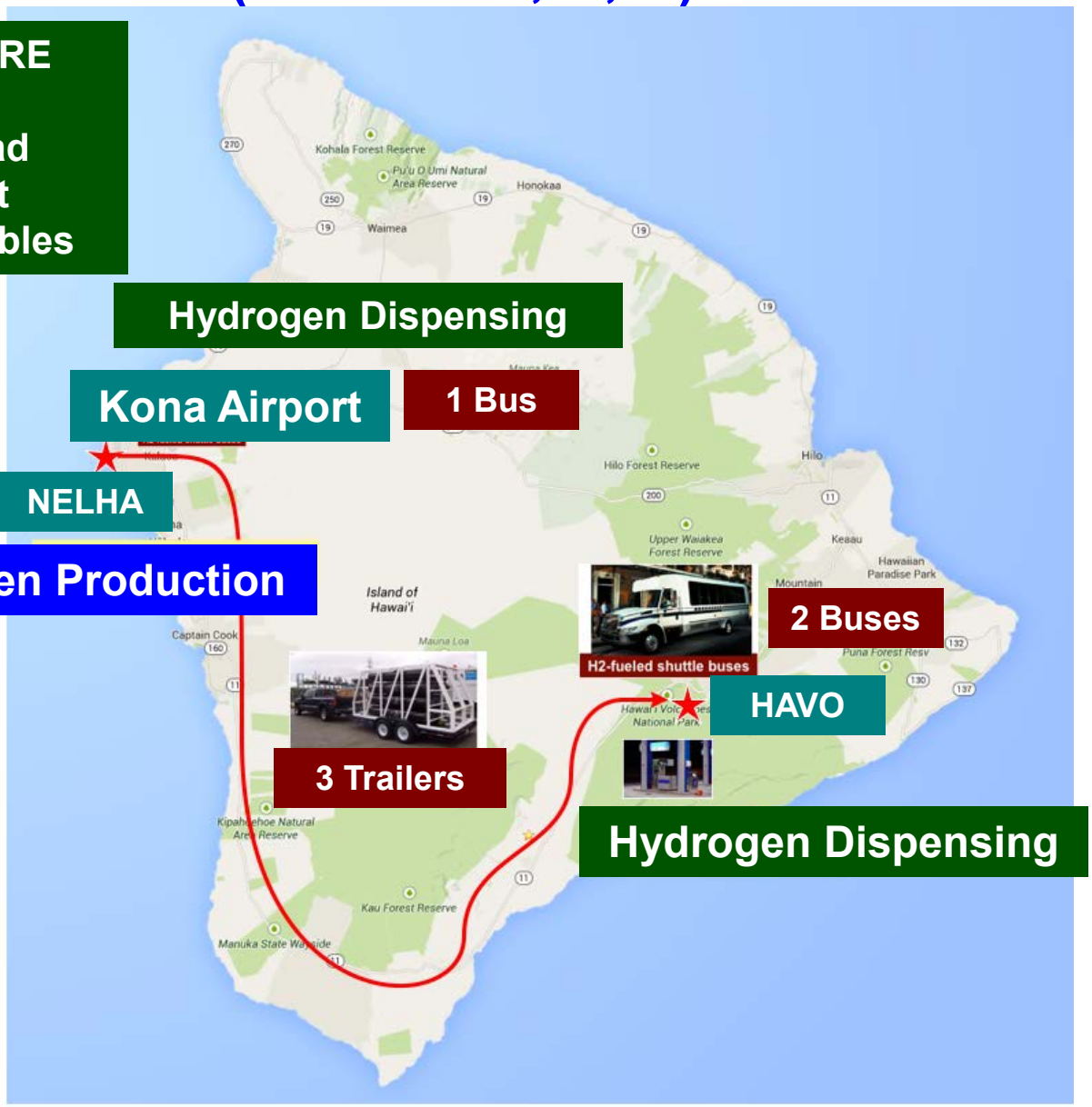
- ✓ **Central site production for highest capital utilization;**
- ✓ **Distributed dispensing sites with minimum complexity;**
- ✓ **Utilize additional revenue streams from monetization of ancillary services;**
- ✓ **Leverage investment in other Hawaii hydrogen projects (e.g. HCATT fuel cell buses)**

Approach: Utilize Lowest Cost Available Renewable Energy Resources (Barriers A,C,H)

- ✓ **Puna Geothermal Ventures - in spite of announcement PGV did not execute MOA;**
  - **Lava outbreak threatened closure of road access;**
- ✓ **Optional sites evaluated;**
- ✓ **NELHA site selected.**
  - **State of Hawaii facility: Strong political support;**
  - **Initially operate using grid power – 30% renewable energy;**
  - **NELHA has variety of potential on-site renewable energy sources:**
  - **Ease of permitting;**
  - **Existing infrastructure reduces site improvement costs;**
  - **Next to Kona Airport: Opportunity to leverage project to support airport ground handling equipment and rental car shuttle buses.**

Approach: Central Site Production/Distributed Dispensing (Barriers A, C, H)

NELHA Potential RE Sources
OTEC: Base Load
PV: Intermittent
Grid: 30% Renewables



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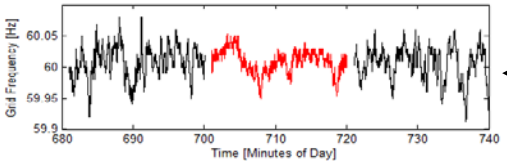
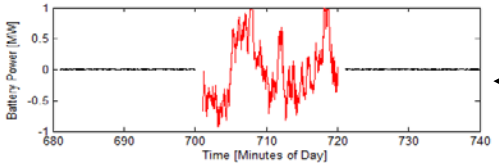
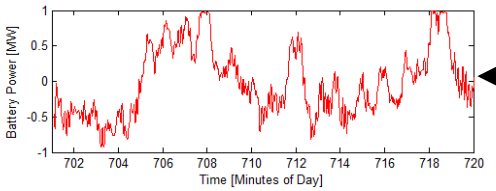
Approach: Replicate BESS Operation Using Electrolyzers for Grid Frequency Regulation (Barrier H)



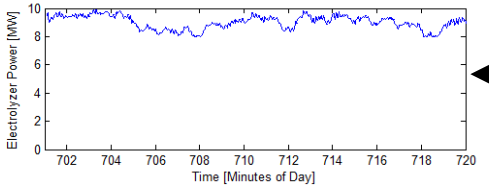
Grid Frequency (Hz): Measured with battery off (black) and on (red) at twenty(20) minute intervals



Battery Output (MW): Can alternate between charge and discharge up to 10 times per second



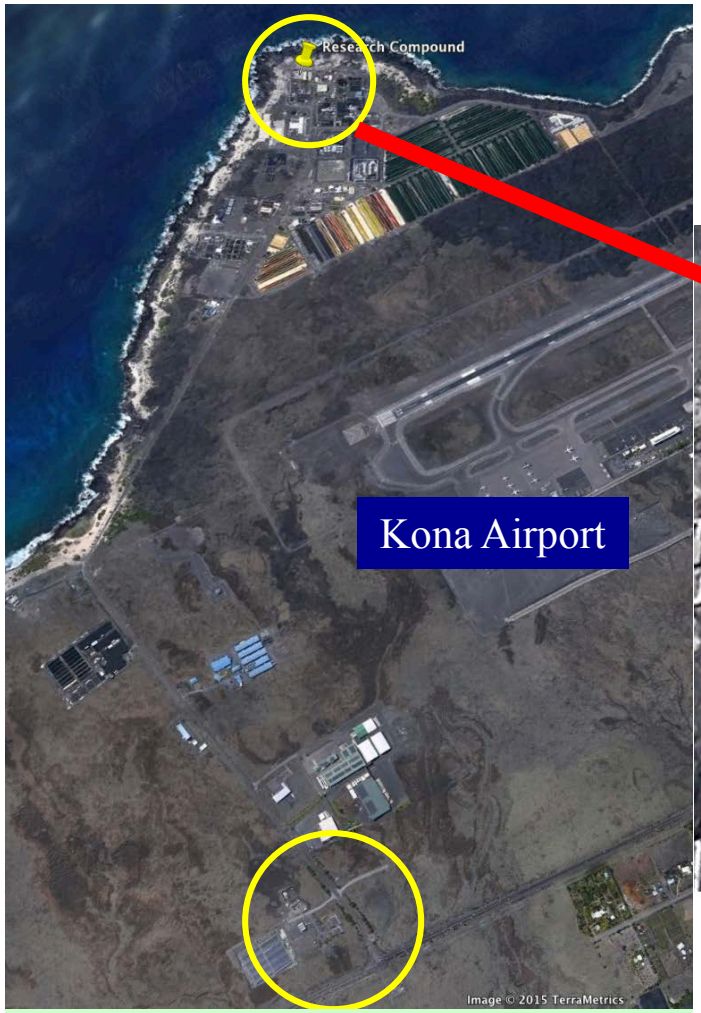
Battery Output (MW): Expanded scale



10MW Electrolyzer: variability in power consumption to provide same frequency support as 1 MW battery

Frequency variability on 150MW grid system reduced with a 1MW, 250kwh fast BESS. Same power range as 1MW BESS easily achieved with 'low' stress and good CAPEX utilization using 10 MW-scale electrolyzers.

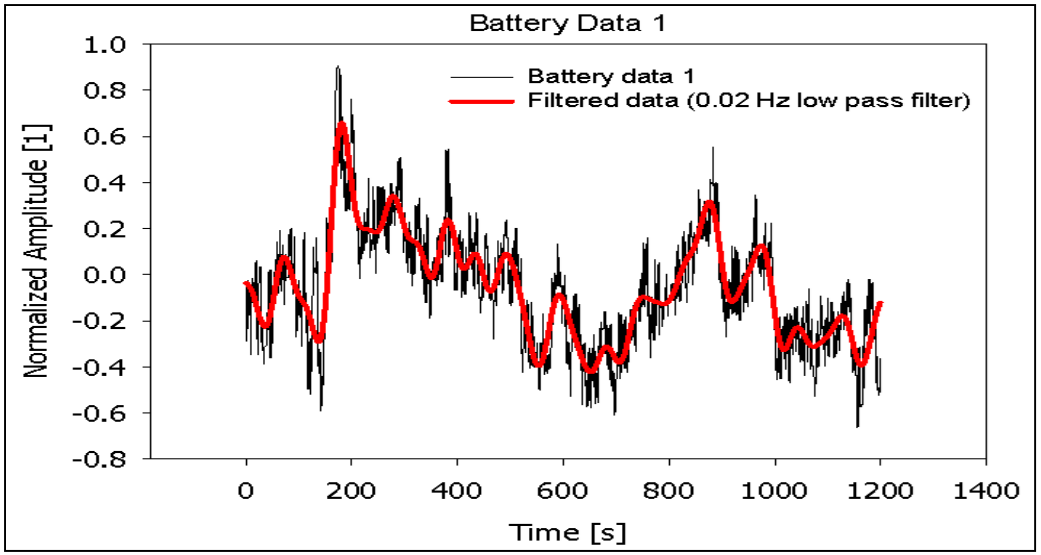
Accomplishment: Site Design Initiated (Barriers A,C)



Original Proposed Site at Gateway Energy Center

Selected Site Layout

Accomplishments: Developed Test Plan (Barrier H)



BESS Measured Load Profile

- **Initial testing at cycle rates (ramp rates) below BESS ramp rates;**
- **Electrolyzer and controls being evaluated to determine maximum allowable ramp rates;**
- **Repeated cyclic operation at "high" rates planned for durability testing .**

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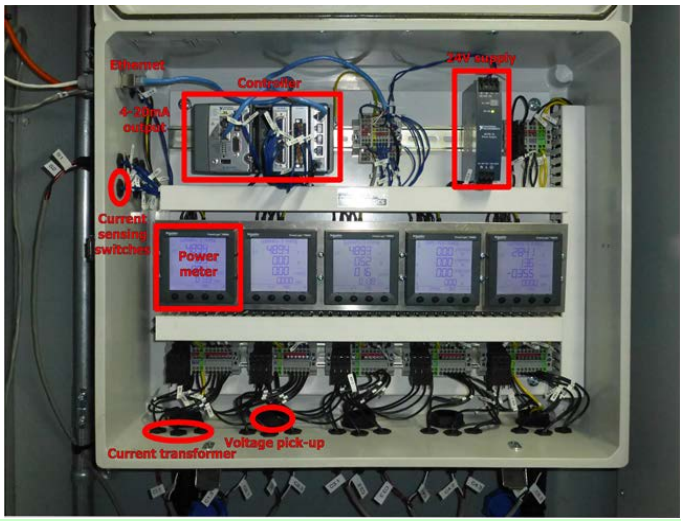
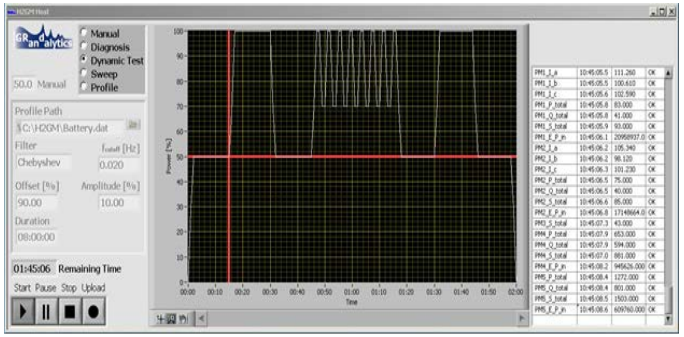
Accomplishments: HNEI Developed PLC and Power Monitoring System

Industry supplied controls not sufficiently flexible to control electrolyzer for grid regulation.



HNEI PLC and Power Monitoring Unit

- ✓ **HNEI developed real-time PLC for control and measurement:**
  - ➢ Imbedded simulation tool;
  - ➢ Provides controls signals to industry management system to maintain safety;
  - ➢ Logs measured data to server;
  - ➢ Test performs self-governing on the real-time controller;
  - ➢ Advanced HMI for simpler control and monitoring.



HNEI PLC Human-Machine Interface (HMI) Screenshot

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Accomplishment: Leveraged Knowledge Gained from Operating MCBH Hydrogen Station

MCBH Hydrogen Station

- Started ops 12/14;
- 350/700 bar "Fast Fill"
- Unattended Operation;
- Over 200 fills

✓ **HNEI MCBH team is testing grid H2 system at Powertech:**

- Good working relationship with supplier personnel;
- Similar equipment – compressor, electrolyzer, dispenser, hydrogen transport trailers;
- Similar Powertech PLC programming;
- Similar O&M requirements;
- HNEI Data Acquisition System also being utilized at MCBH.

✓ **Projected Results: Smoother implementation at NELHA.**

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Accomplishment: Testing Initiated at Powertech

Due to siting delays system testing initiated at Powertech

- ✓ **Jump-starts the testing phase;**
- ✓ **5-month test period supervised by on-site HNEI staff;**
- ✓ **Leverages experience with MCBH hydrogen system:**
  - ➢ **Commissioning new designs is complex;**
  - ➢ **Takes much longer than originally assumed – 10 months for MCBH system;**
  - ➢ **Supporting systems 2,500 miles away difficult and expensive;**
  - ➢ **Debug the hardware and software systems at factory;**
  - ➢ **Spare parts readily available;**
  - ➢ **Simplifies installation in Hawaii – becomes true "Plug & Play".**

Accomplishments: Summary

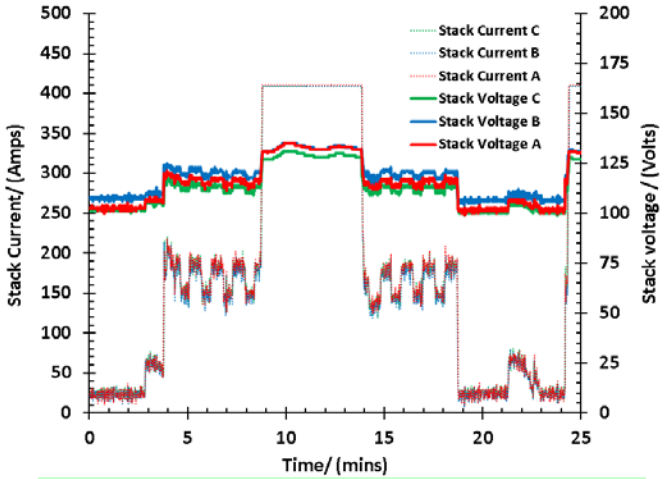



- **Commissioning completed using Powertech PLC;**
- **Installed HNEI PLC system to control cycling experiments;**
- **Conducted commissioning tests with system PLC and HNEI PLC**
  - **Individual component functionality evaluation;**
  - **Electrolyzer diagnostic tests on regular basis to determine the degradation over the long-term.**
- **Conducted system performance test with HNEI PLC**
  - **Conducted sweep load profile to determine operating envelope & system limits;**
  - **Tested reliability of HNEI PLC to control and operate the electrolyzer safely.**
- **Started electrolyzer cycling test with HNEI PLC.**

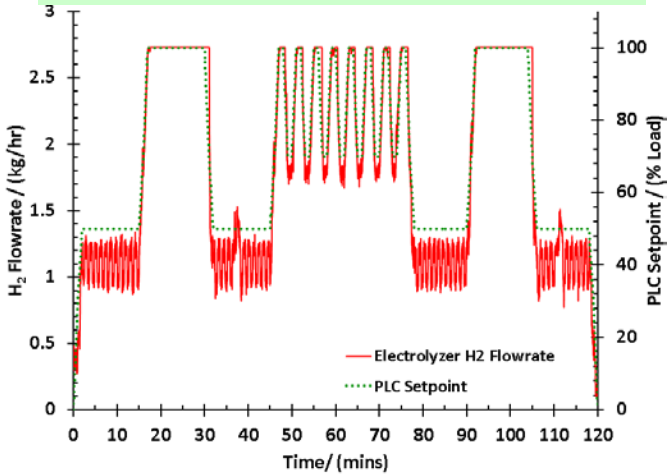
Accomplishments: Initial Test Data Results

Successfully commissioned the PLC and Power monitoring system

- ✓ **Electrolyzer diagnostic test:**
  - ➢ Initial stack voltages and ramp rates were measured and logged at maximum current demand;
  - ➢ Current oscillations observed at ≤ 50% load demand.
- ✓ **HNEI PLC commissioning test:**
  - ➢ PLC controlled and operated the electrolyzer safely and reliably;
  - ➢ Fine tuning of the system PLC input signal is required to synchronize with electrolyzer output.



Diagnostic Test to Monitor Degradation Over Time



Demo Ability to Control Electrolyzer Power Levels

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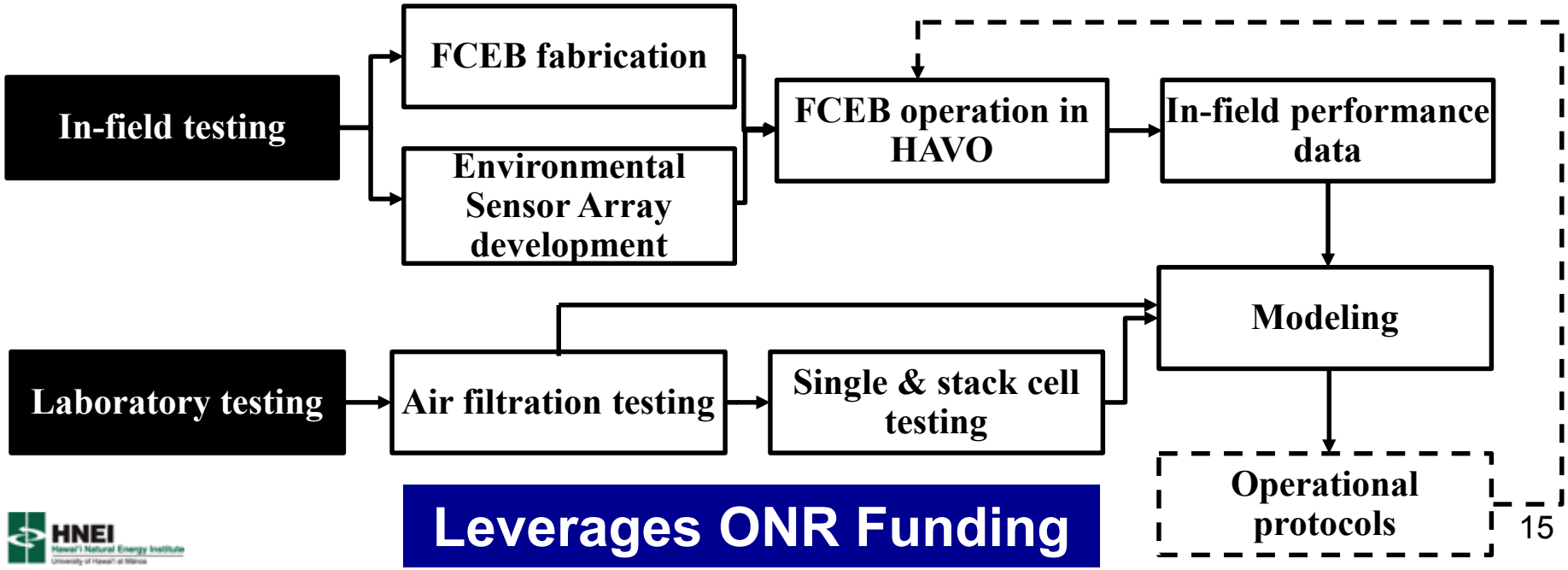
Accomplishments: Leverage Project – Supply Hydrogen for HAVO Fuel Cell Bus Air Filtration System Development

Develop and demonstrate operating protocols for fuel cell electric buses (FCEB) operating in harsh environment

- ✓ Completed single cell testing with HAVO air contaminant mixtures;
- ✓ Completed laboratory testing of commercial air filters;
- ✓ Developed operating protocols for fuel cell bus;
- ✓ Completed FCEB bus fabrication and installed onboard Environmental Sensor Array (ESA).



Leverages ONR Funding

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Responses to Previous Year Reviewer's Comments

- ✓ **FY14 Reviewer Comment: There is some discord between the identified barriers and the project objectives.**
  - ➢ **FY15 Response:**
    - **Upon reflection this is a fair comment. We have adjusted the barriers and included Barrier H which addresses the lack of awareness of the utility industry to the potential of renewable hydrogen storage applications. The use of an electrolyzer to help manage grid frequency while at the same time producing a value added transportation fuel is of real interest to the electric utilities and will be communicated to them when we have collected and analyzed data.**
- ✓ **FY14 Reviewer Comment: The success of the program is based on the ability to cycle electrolysis cells. If there are data to show this is not an issue, they should be shown; if not, data should be collected early, even if at the cell level.**
  - ➢ **FY14 Response:**
    - **We concur. To address this we have initiated a test program at Powertech in advance of setting up the system in Hawaii. There are many benefits to this which we have highlighted in our presentation.**

Collaborations

- ✓ **US Department of Energy: Project Sponsor & Funding;**
- ✓ **Naval Research Laboratory: Federal Technical Program Manager;**
- ✓ **Hawaii Natural Energy Institute: Implementing Partner, Technical Lead;**
- ✓ **Office of Naval Research: Supplemental Funding;**
- ✓ **State of Hawaii: Public Outreach, Cost Share;**
- ✓ **Natural Energy Laboratory Hawaii Authority: Host Site;**
- ✓ **County of Hawaii Mass Transit Agency: Host Site, Bus Operator (Cost Share);**
- ✓ **Hawaii Volcanoes National Park: Host Site, Bus Operator;**
- ✓ **HCATT: Conversion of Shuttle Bus, Cost share;**
- ✓ **US Hybrid: Conversion of Shuttle Bus, Cost share;**
- ✓ **HELCO: Interested Observer, Potential Partner for Grid Analysis;**
- ✓ **Hydrogen Safety Panel: Design Hydrogen Safety Review;**
- ✓ **PNNL: First Responder Training;**
- ✓ **Boyd Hydrogen: Site Hydrogen Safety Review.**

Remaining Challenges and Barriers

- ✓ **Complete NELHA site improvements.**
- ✓ **Install and commission hydrogen production system by 30/09/15;**
- ✓ **Overcome software and hardware “punch lists”;**
- ✓ **Install dispensing systems at HAVO and Kona airports;**
- ✓ **Launch a public outreach plan that effectively addresses community concerns.**

Proposed Future Work

- ✓ Complete infrastructure at NELHA 07/15
- ✓ Install infrastructure at HAVO & MTA sites 08/15
- ✓ Complete MTA shuttle bus conversion 9/15;
- ✓ Operate systems 1/15 – 09/15;
- ✓ Collect & analyze data 1/15 – 09/15;
- ✓ Prepare performance reports 1/15 – 09/15.

This project ends on 30 September 2015. Using other funds HNEI intends to operate the systems and continue to gather additional data beyond the completion date of the US DOE portion of the project in order to develop hydrogen infrastructure to support existing and future hydrogen projects in Hawaii (Barriers A,C,H).

Summary

Objective: Demonstrate the performance and cost benefits of grid integrated hydrogen systems.

Relevance: Electrolysis of water to produce hydrogen could contribute significantly to Hawaii fuel needs while providing needed support for grid connected intermittent renewables;

Added value of using electrolyzer to provide grid ancillary services will expand market opportunities.

Will help validate costs required to justify large scale electrolysis for fuel production.

Approach: Central site production. Distributed dispensing. Seek sites with potential for low cost renewable energy production. Validate durability and performance under sustained cyclic operation. Deliver hydrogen to FCEV bus operators. Demonstrate performance to operators and public;

Accomplishments: Completed analysis and test plan. Built and installed data acquisition and control system for the hydrogen system. Executed test contract with Powertech Labs. Commissioned H2 system at Powertech. Conducted initial testing at Powertech. Secured test site at NELHA. Installed site improvements. Progressed conversion of MTA bus. Started installation of dispensers at HAVO and Kona airport (MTA bus).

Collaborations: Strong & dedicated team comprised of cooperating federal departments (DoD, US DOE, NPS), State, County, and private industry.

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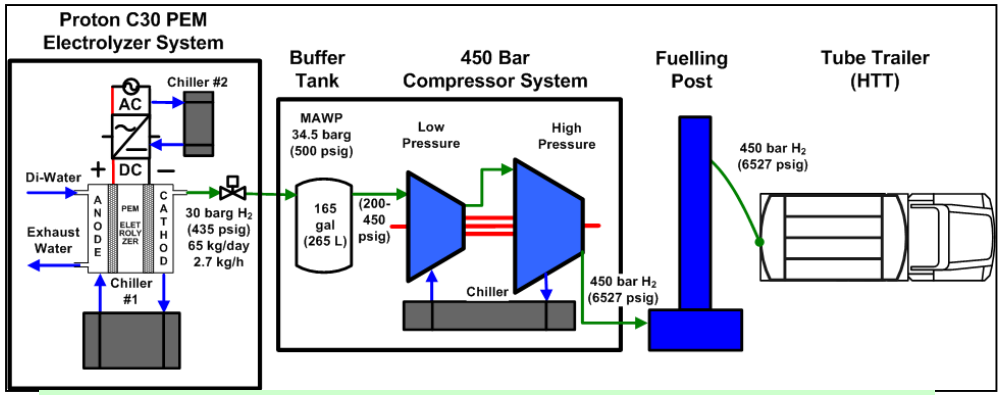
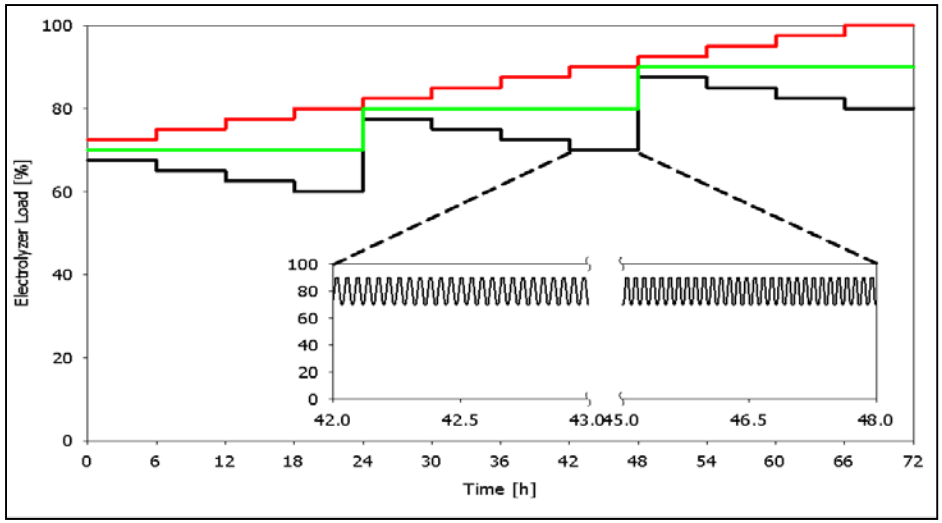
Technical Back-Up Slides

Sweep Load Profile



Electrolyzer Grid Management System



Sweep Load Profile

- **Electrolyzer output controlled by sinusoidal profile of continuously increasing frequency over 6 hours;**
- **Sweeps repeated at different amplitudes and offsets;**
- **Profile calculated from parameters - can be easily adapted;**
- **Tests shall determine interaction of components and maximum dynamics of the system.**

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