2016 Hydrogen and Fuel Cells Program Annual Merit Review Meeting

Hydrogen Energy Systems as a Grid Management Tool

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June 9, 2016 **Project: MT008**

Acronyms

✓	BESS:	Battery Energy Storage System
✓	CAPEX:	Capital Expense
✓	DoD:	Department of Defense
✓	FCEV:	Fuel Cell Electric Vehicle
✓	H2:	Hydrogen
✓	HAVO:	Hawaii Volcanoes National Park
✓	HCATT:	Hawaii Center for Advanced Transportation Technology
✓	HELCO:	Hawaiian Electric Light Company
✓	HES:	Hydrogen Energy System
✓	HNEI:	Hawaii Natural Energy Institute
✓	HTT:	Hydrogen Transport Trailer
✓	MTA:	Mass Transit Agency
✓	NELHA:	Natural Energy Laboratory Hawaii Authority
✓	NPS:	National Park Service
✓	NRL:	Naval Research Laboratory
✓	O&M:	Operations and Maintenance
✓	ONR:	Office of Naval Research
✓	PLC:	Programmable Logic Controller
✓	PNNL:	Pacific Northwest National Laboratory
✓	PV:	Photovoltaic
✓	RFQ:	Request for Quotation

Overview

Timeline

- ✓ **Project start date: 30 Sep 10**
- ✓ **Project end date: 29 Sep 15**
- ✓ **Project continued using non USDOE funds**

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 4/15/16: $4,060,000**
- ✓ **Total Project Value : $5,040,000**
- ✓ **Cost Share %: $3,000,000 (60%)**

Partners

Cost Share Partners

- ✓ **US DOE:** Project Sponsor & Funding
- ✓ **NRL:** Federal Technical Program Manager
- ✓ **HNEI:** Implementing Partner, Technical Lead
- ✓ **NELHA:** Host site and Cost Share.
- ✓ **County of Hawaii:** Bus Operator & Cost Share
- ✓ **State of Hawaii**: Cost Share
- ✓ **ONR:** Cost Share

Related Supporting Projects

- ✓ **HCATT:** Bus Conversion
- ✓ **US Hybrid:** Bus Conversion

Relevance

Grid Frequency Management

- ✓ Electric power grids operate at a frequency of 60 Hz;
- ✓ Deviation from 60 Hz is a measure of the load balance of the grid – load matched to generation;
- ✓ With increased penetration of intermittent renewables on the grid not only the load but the supply is subject to fluctuations.
- ✓ Grid operators attempt to stabilize the frequency by ramping power generation up/down;
- ✓ Battery can be a useful source/sink of power reducing the need for the utility to operate power generation at lower efficiencies and incurring higher costs;
- ✓ Project Thesis: An electrolyzer can be used as a variable controllable load that can be reduced/increased when other loads increase/decrease in order to maintain the total balance and the frequency stable;

Relevance

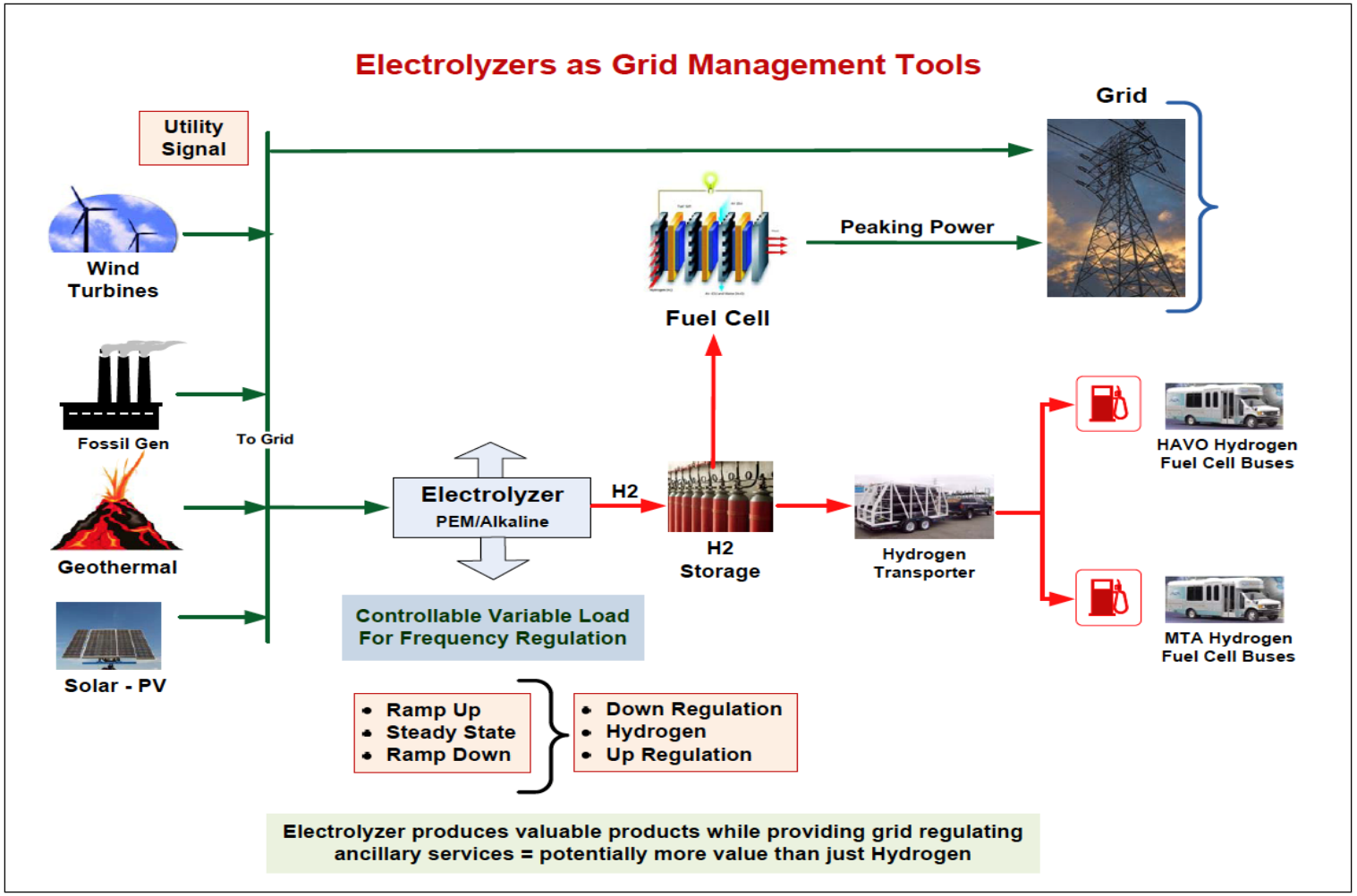
Project Objectives

- ✓ **Validate the performance, durability & cost benefits of grid integrated hydrogen systems (Barriers C & H);**
  - ➢ **Demonstrate dynamic operation of electrolyzer to mitigate impacts of intermittent renewable energy (Barrier H);**
  - ➢ **Demonstrate potential of multiple revenue streams from monetization of ancillary services and producing hydrogen;**
  - ➢ **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

- ✓ **Completed 7 months of system testing & analysis (Barrier H);**
- ✓ **Demonstrated hydrogen system has potential to support grid frequency regulation. Provides path for increasing amount of renewables on the grid. (Barriers C & H);**
- ✓ **Completed site design and safety analysis; issued RFQ and selected contractor for NELHA site infrastructure (Barriers A & C).**

Approach

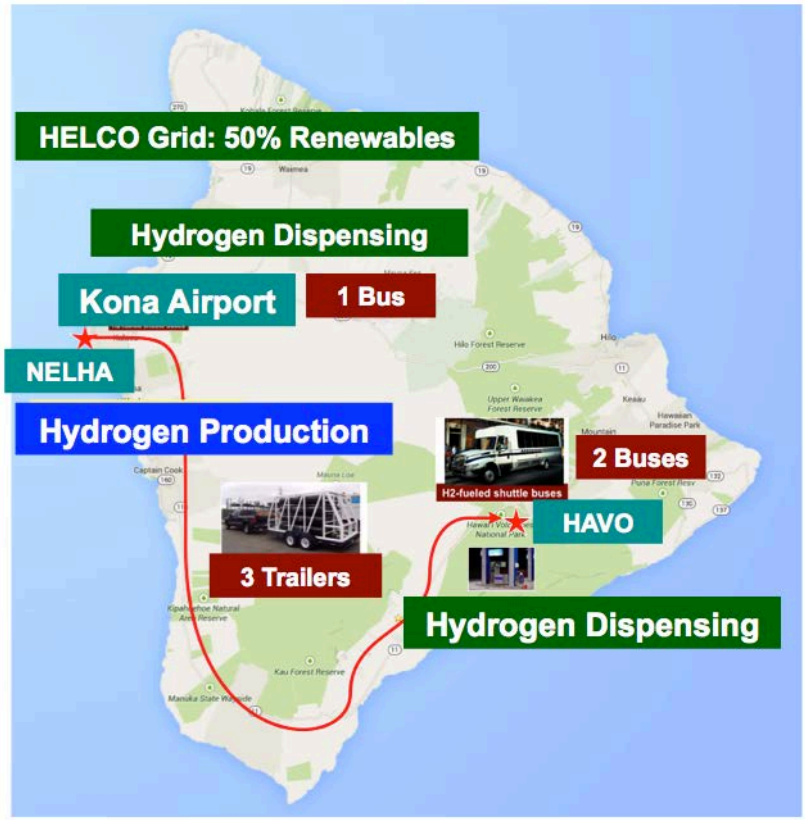


HNEI's concept to use an electrolyzer for fast demand response to provide grid ancillary services such as up-regulation, down-regulation, and off-peak load.

Approach

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

Economically viable electrolytic hydrogen will require low cost electricity + high capital utilization.



- ✓ **Central site production for highest capital utilization;**
- ✓ **Distributed dispensing sites with minimum complexity to reduce fuel distribution costs;**
- ✓ **Optimize additional revenue streams from:**
  - ➢ **Quantify and monetize ancillary services;**
  - ➢ **Sale of hydrogen for transportation**

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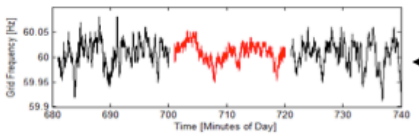
Approach
Install Project at NELHA (A,C,H)

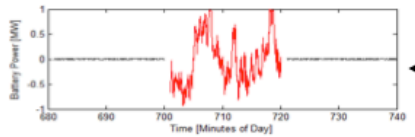
- State of Hawaii facility:
  - Strong political & financial support;
  - Significant cost share provider;
  - Available staff.
- Ease of permitting;
- Existing infrastructure reduces site improvement costs;
- Proximity to Kona Airport offers opportunity to leverage project:
  - Airport ground handling equipment;
  - Airport shuttle buses;
  - Rental cars.
- Support NELHA Vision of a “Hydrogen Hub”;
  - This project provides “enabling” infrastructure to attract new projects;

Approach

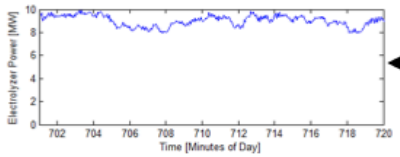
Use BESS* Operation as Model for Using Electrolyzer for Grid Frequency Regulation (H)



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 up to 10 times per second



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 (*BESS separate project using Lithium-Titanate battery on HELCO Grid);**
- **Model suggests same power range as 1MW BESS can achieved with good CAPEX utilization using 10 MW-scale electrolyzer;**
- **Early operation suggests electrolyzer more appropriate for slower-acting changes;**
- **Project will investigate electrolyzer/BESS hybrid to find optimum mix of battery and electrolyzer to provide required level of grid regulation services.**

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Accomplishments

Completed Equipment Commissioning & Testing




- **Installed and commissioned HNEI PLC system for improved control of cycling;**
- **Completed the following:**
  - **Individual component functionality evaluation;**
  - **Electrolyzer diagnostic baseline tests. Tests at regular intervals over the 2-year duration of the project will be used to determine electrolyzer degradation over the long-term;**
  - **Conducted sweep load profile to determine operating envelope & system limits;**
  - **Tested reliability of HNEI PLC to control and operate the electrolyzer safely.**

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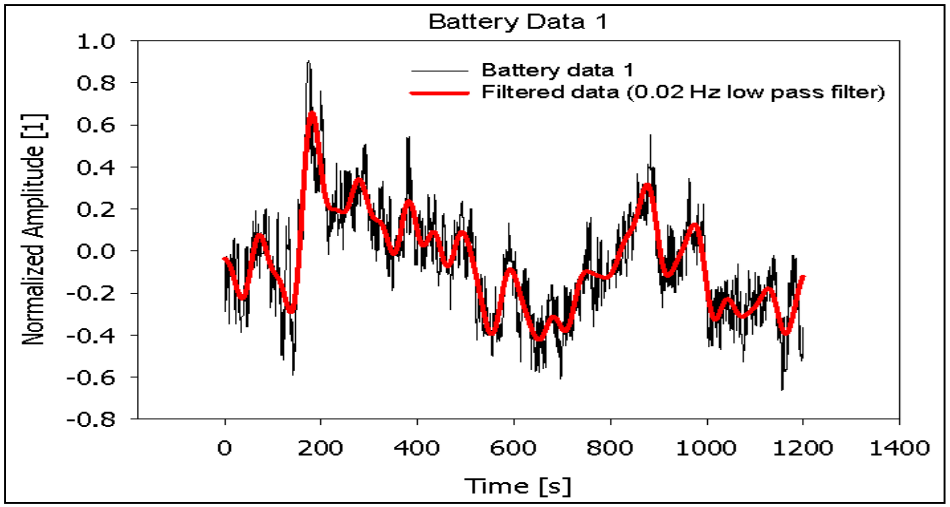
Accomplishments

Initial Test Plan (H)



BESS Measured Load Profile

- **Initial testing at cycle rates (ramp rates) below BESS ramp rates;**
- **Electrolyzer and controls evaluated to determine maximum allowable ramp rates;**
- **Repeated cyclic operation at "high" rates planned for durability testing;**
- **Dynamic model will be developed and used to evaluate electrolyzer/BESS hybrid performance.**

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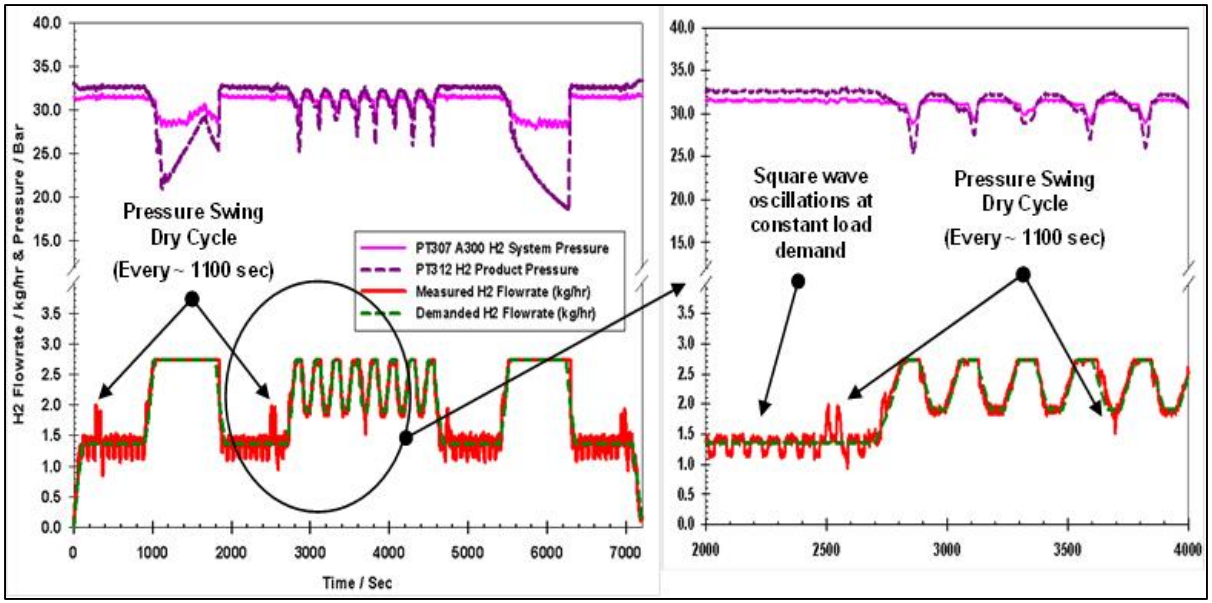
Accomplishments

Load Profile Test Using HNEI PLC

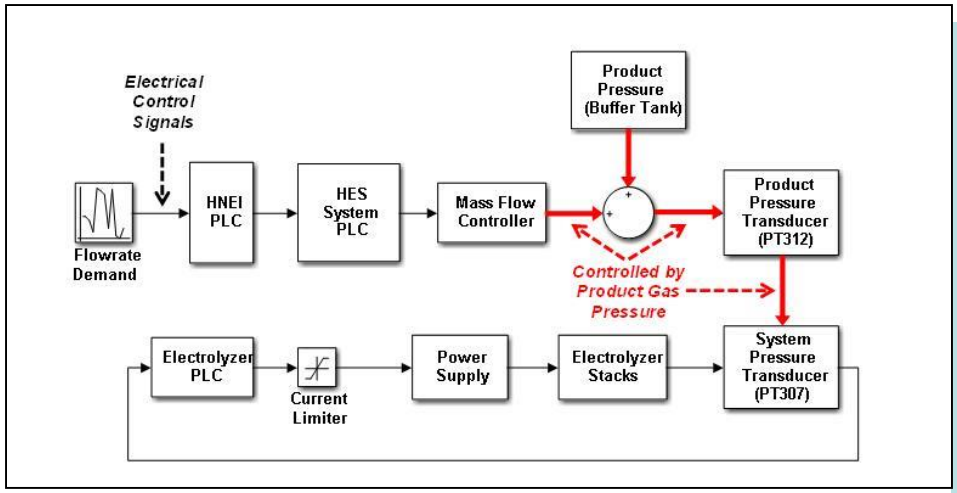


Results of a initial load profile test using the HNEI PLC

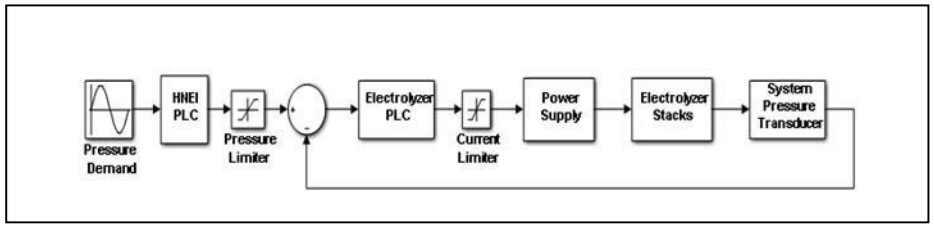
- **Operation of the HES for hydrogen production for fueling fuel cell-battery hybrid shuttle buses was very acceptable;**
- **Use of the HES for the grid management was not suitable with the factory installed electrolyzer control system.**

Accomplishments

Modified Electrolyzer Control System Algorithm



Original Electrolyzer Control System Algorithm



Modified Electrolyzer Control System Algorithm

- ✓ Electrolyzers can respond quickly to changes in load;
- ✓ Commercial hydrogen production systems not optimized for dynamic operating profiles, particularly in the areas of power conversion & controls;
- ✓ HNEI modified control algorithm made response of the system ~10 times faster but still not fast enough to match BESS performance.
- ✓ Electrolyzer/BESS hybrid may be the solution.
- ✓ Initiated dialogue with Proton Onsite to collaborate on further control system modifications.

Accomplishments

Hydrogen Energy System (HES) Analysis

HES = Electrolyzer System + Compressor + Auxiliaries

Measured power consumption and parasitic loads over 24 hour period to determine overall system efficiency

- ✓ **Data collected by database of electrolyzer and HNEI PLC ;**
- ✓ **Produced 65 kg of hydrogen, compressed to 450 bar and stored in hydrogen transport trailer;**
- ✓ **HES total power consumption: 79 kWh/kg**
- ✓ **HES overall efficiency: 50%**
- ✓ **90% of total energy consumed by electrolyzer system;**
- ✓ **10% consumed by compressor and auxiliary loads.**

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Accomplishments

Buses & Hydrogen Transport Trailers

County of Hawaii Bus (1)

HAVO Bus (2)

Hydrogen Transport Trailer (3)

- Fuel Cell Electric Hybrid Shuttle Buses demonstrate to the general public the advantages of fuel cell buses and electric drive.
  - Quiet ride
  - No diesel fumes.
  - Potential for lower O&M costs (need low cost hydrogen);
- HAVO Buses will demonstrate HNEI's "Smart" air filtration sensor systems in a high air contaminant environment (funded by ONR);
- Hydrogen Transport Trailer carries 105 kg @ 450 bar. They will demonstrate distributed dispensing using cascade fill to 350 bar using a "Smart" dispenser.
- Trailer O&M costs will be evaluated including US DOT hydrostatic testing requirement every 5 years.
  - Currently no facility in Hawaii can hydro test cylinders of this size:
  - Must be shipped to mainland (very costly and time consuming).

Accomplishment:
Installation Underway (A,C)

Site Layout

- ✓ **Boyd Hydrogen conducted workshop on NFPA-2 Hydrogen Technologies Code (2016) for County of Hawaii permitting officials and senior fire department leadership;**
- ✓ **Received planning department Plan Approval for site infrastructure April 7, 2016.**
- ✓ **Complete equipment installation by August 2016**

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Responses to Previous Year Reviewer's Comments

- ✓ **FY15 Reviewer Comment: Lack of installed equipment is a weakness.**
  - ➢ **FY16 Response:**
    - **Agree. We have mitigated this issue by deploying staff to the Powertech site and operated the system for 7 months to collect and analyze initial data while at the same time identifying and rectifying equipment issues. After defects were rectified, staff were again deployed in Feb 2016 to operate the system, investigate potential mods to controller, and collect additional data.**
- ✓ **FY15 Reviewer Comment: More economic data showing cost components was needed.**
  - ➢ **FY16 Response:**
    - **To date the actual cost of components is proprietary information of both Powertech and its major equipment suppliers. We will request permission to release this data for subsequent reports. Going forward we plan to prepare economic models that address the O&M costs of running the system which are substantial and need to be documented so that the full cost of these systems can be appreciated and incorporated into "total cost of ownership" models. We have included one slide on system efficiency data and the energy use in kWh/kg.**

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; Site Work**
- ✓ **County of Hawaii MTA: 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.**
- ✓ **Proton Onsite: Electrolyzer Control System**
- ✓ **Aloha Petroleum: Hydrogen Delivery**

Remaining Challenges and Barriers

- ✓ Reduce project delays by anticipating speed bumps;
- ✓ Stretch dwindling budget by leveraging existing designs, partners & infrastructure;
- ✓ Complete NELHA site improvements;
- ✓ Install and commission hydrogen systems at NELHA;
- ✓ Conduct MTA bus operations at NELHA;
- ✓ Execute MOA & install dispensing system at HAVO;
- ✓ License hydrogen transport trailers for use in Hawaii;
- ✓ Deliver hydrogen to HAVO with Aloha Petroleum;
- ✓ Launch a public outreach plan that effectively addresses community concerns.

This US DOE component of project ended on 30 September 2015. Using other funds HNEI has continued to operate the systems and 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 (A,C,H).

Proposed Future Work

- ✓ Complete infrastructure at NELHA;
- ✓ Install infrastructure at HAVO site;
- ✓ Complete MTA shuttle bus conversion;
- ✓ Evaluate performance of the HAVO buses air filtration system;
- ✓ Conduct further battery profile simulation tests with different low pass filter frequencies & amplitudes;
- ✓ Evaluate the modified electrolyzer control system and design. Implement and validate its operation with electrolyzer.
- ✓ Develop dynamic model of the system using measured characteristics of the modified control algorithm;
- ✓ Evaluate electrolyzer/BESS hybrid design
- ✓ Collect & analyze performance data;
- ✓ Prepare performance reports;
- ✓ Prepare peer-reviewed journal papers.

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's transportation 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.

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

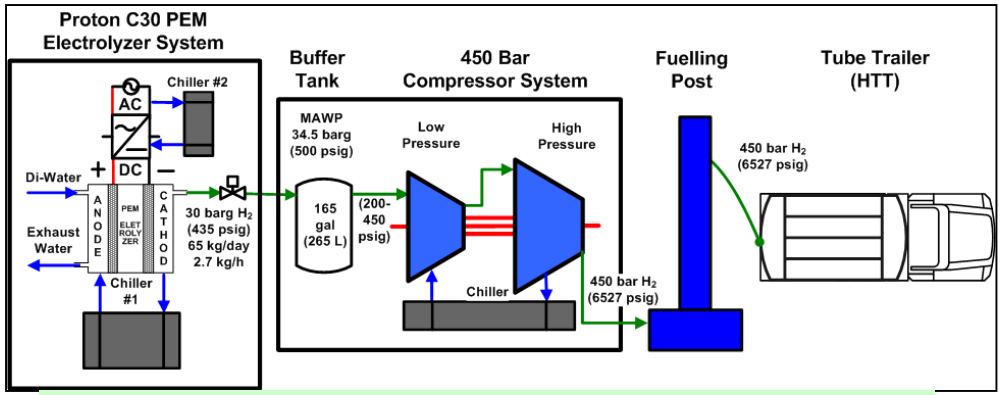
Approach: Central site production. Distributed dispensing. Seek sites with potential for low cost renewable energy production. Validate durability and performance under sustained cyclic operation. Evaluate electrolyzer/battery hybrid designs. Deliver hydrogen to FCEV bus operators. Demonstrate performance to legislators, utilities, operators, and public;

Accomplishments: Commissioned H2 system at Powertech. Conducted 7 months initial testing at Powertech. Secured test site at NELHA. Issued site installation contract. Progressed conversion of MTA bus. Started installation of dispenser at NELHA to support MTA bus. Modified controls algorithm that allowed electrolyzer to operate with faster response time making it suitable for grid frequency management.

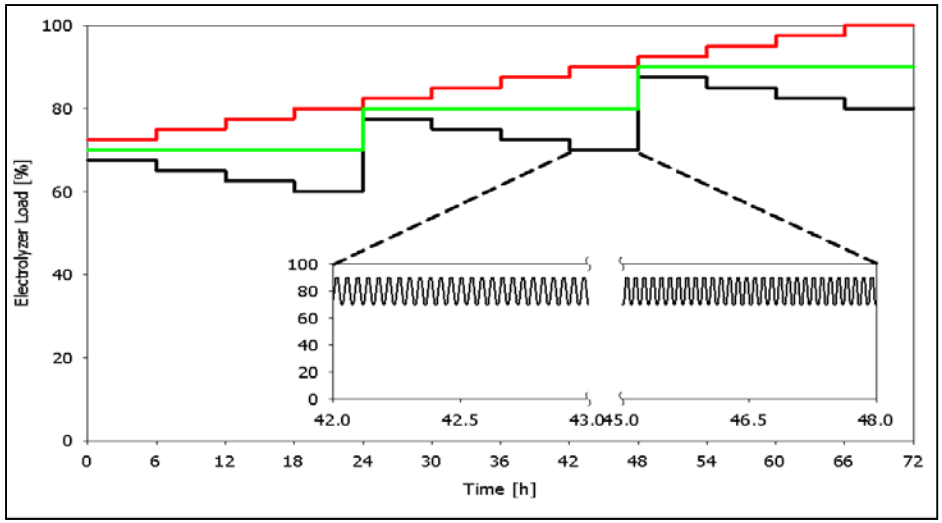
Collaborations: Strong & dedicated team comprised of cooperating federal departments (DoD, US DOE, NPS), State, County, and private industry.

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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