

**2017 DOE Hydrogen and Fuel Cells Program Review**

# **Hydrogen Energy Systems as a Grid Management Tool**

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**June 7, 2017**

**Project: MT008**

# Acronyms

✓ BESS:	Battery Energy Storage System
✓ CAPEX:	Capital Expense
✓ DoD:	Department of Defense
✓ FCEV:	Fuel Cell Electric Vehicle
✓ H <sub>2</sub> :	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

## Budget

- ✓ Expended as of 4/10/17: **\$4,060,000**
- ✓ Total Project Value : **\$5,040,000**
- ✓ Cost Share %: **\$3,000,000 (60%)**

## 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.

## 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

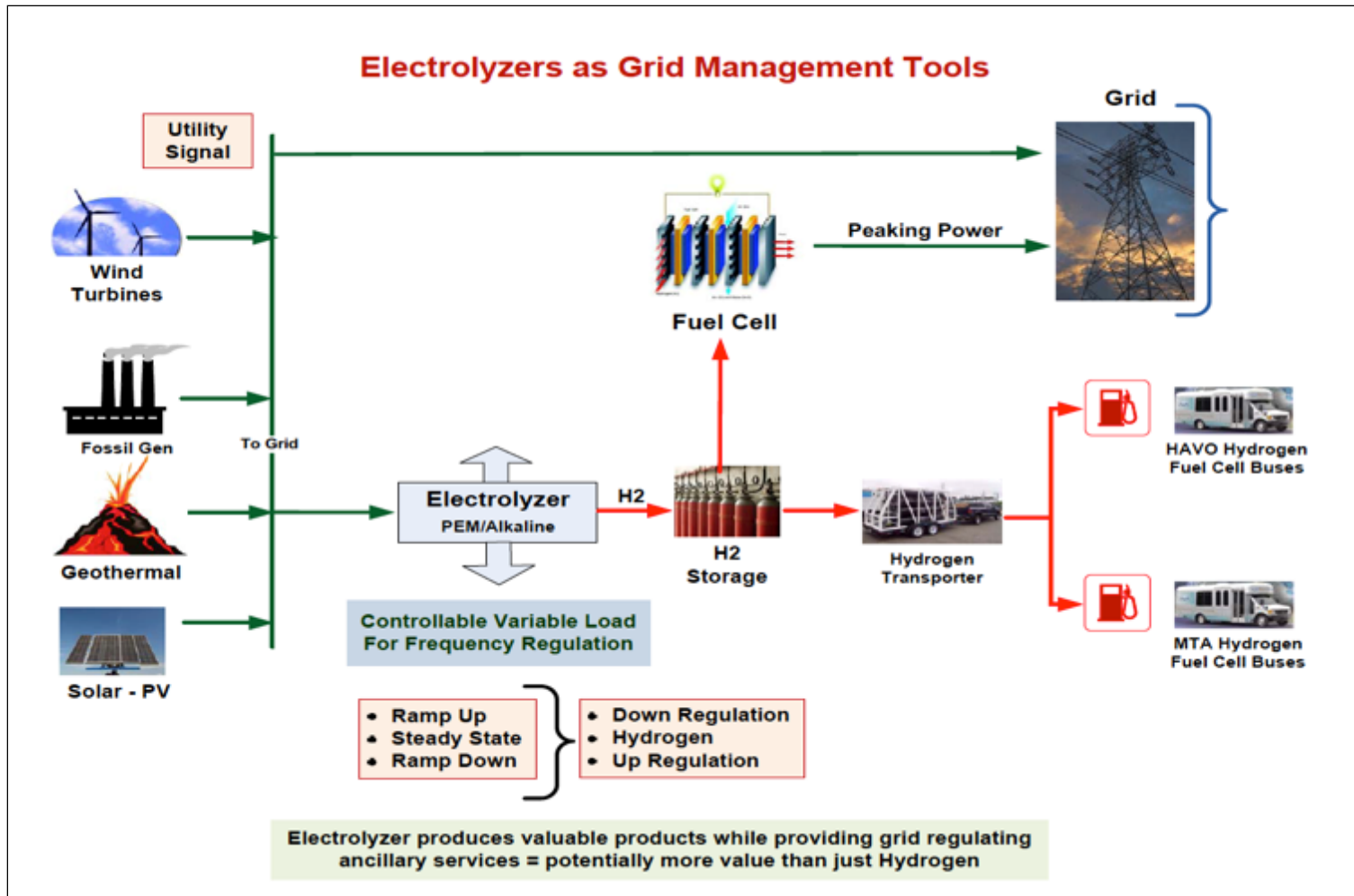
## Project Objectives

- ✓ **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 (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 electrolyzer dynamic modeling tool; (Barrier H);**
- ✓ **Obtained necessary site permits from County of Hawaii; (Barrier A)**
- ✓ **Started NELHA site infrastructure installation;**
- ✓ **Modified hydrogen transport trailers to improve cascade fill utilization from 50% to 90% thus reducing hydrogen transport cost.**

# Approach

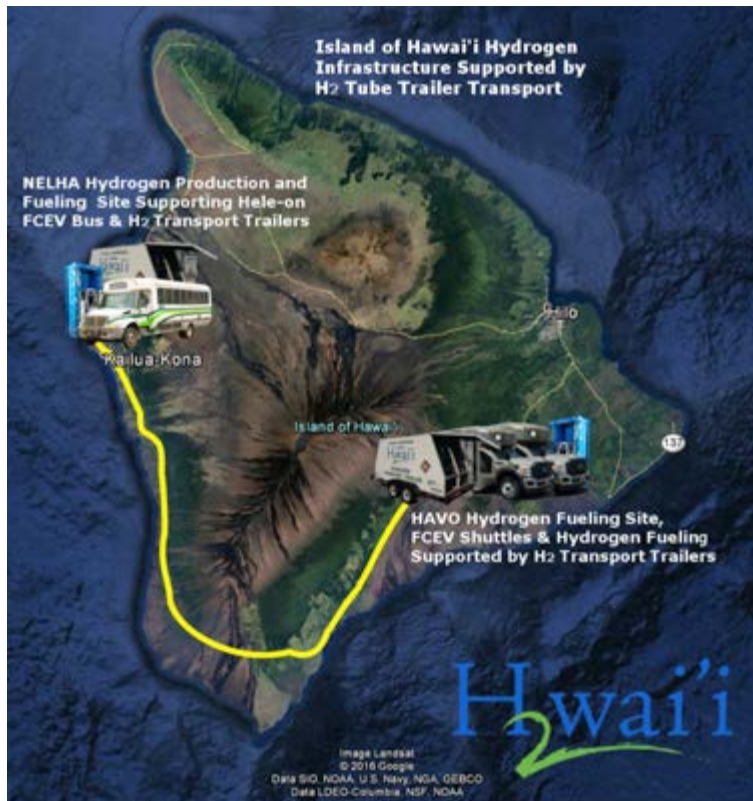


HNEI's concept to use an electrolyzer for fast demand response to provide grid ancillary services such as up-regulation, down-regulation, and off-peak load.

## 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.

## Approach

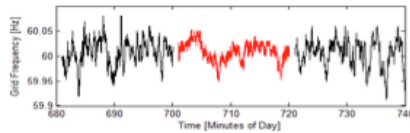
# Install Project at NELHA (A,C,H)

- **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.

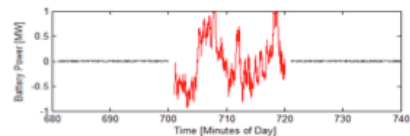


## Approach

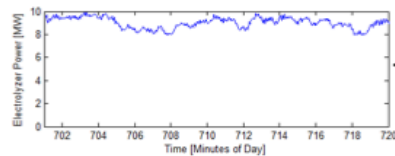
# Use BESS Operation as Model for Using Electrolyzer for Grid Frequency Regulation (H)



**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 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.

# Accomplishments Installation Underway (A,C)



## Site Layout



# Accomplishments Equipment Delivered

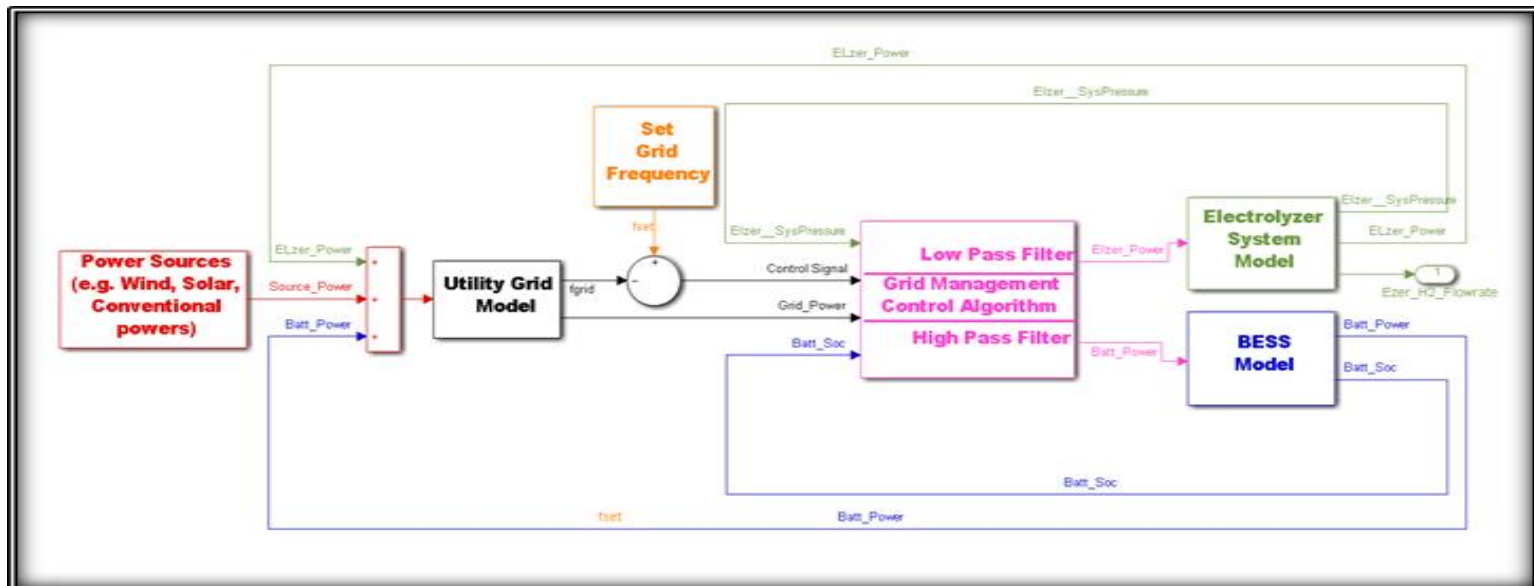


# Accomplishments

## Simulation Analyzer for HES Grid Management Application

### Objectives of the Hydrogen Energy System (HES) Simulation Analyzer:

- Characterize the performance of HES system under realistic dynamic or cyclic Hawaiian island grid demand profiles;
- Develop, evaluate and optimize the grid management control algorithms for different island renewable power resources and fluctuating grid demand;
- Study the sizes (kW  $\Rightarrow$  MW) tradeoffs between electrolyzer systems and storage systems required for different renewable power resources;
- Evaluate the performance of a hybrid system (Electrolyzer + Battery Energy Storage System) with different control algorithms and grid demand profiles.



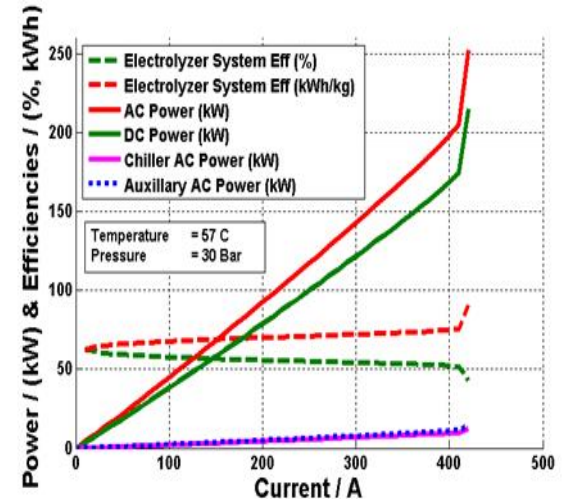
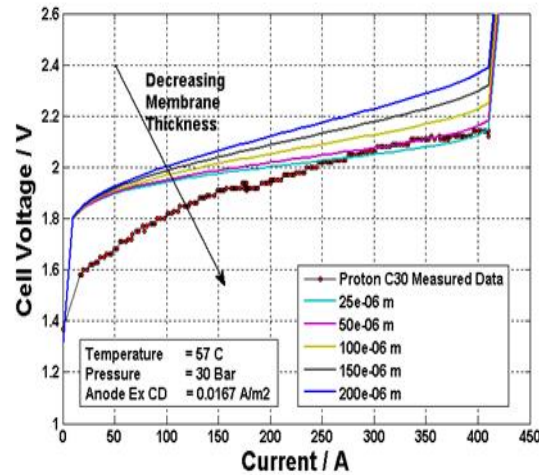
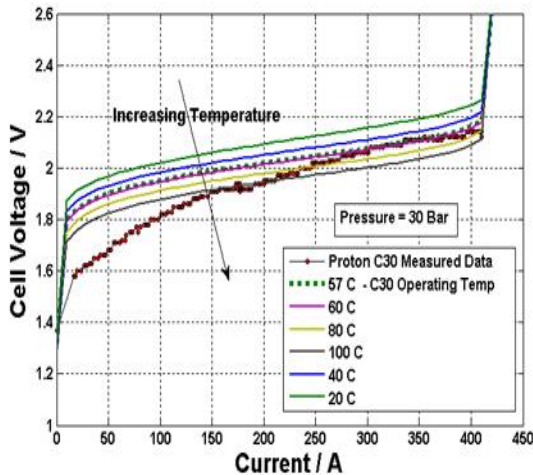
# Accomplishments

## Electrolyzer System Model

- Model determines electrolyzer cell voltage ( $V_{\text{cell}}$ ) as function of different operating conditions such as current, pressure, temperature, membrane thickness, etc.

$$V_{\text{cell}} = V_o + \eta_{\text{act, a}} + \eta_{\text{act, c}} + \eta_{\text{ohmic}} + \eta_{\text{con}}$$

- Model employed to predict the performance of a commercial PEM electrolyzer to estimate the system (DC & AC) power demands and the operating efficiencies required for development of grid management control algorithms.





# Accomplishments

## Converted 3 Buses



County of Hawaii Bus (1)



HAVO Bus (2)

- **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).**

# Accomplishments

## Purchased 3 Hydrogen Transport Trailers



- **Hydrogen Transport Trailer carries 105 kg @ 450 bar;**
- **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).**

# Responses to Previous Year Reviewer's Comments

- ✓ **FY16 Reviewer Comment: Not clear on the reason for all the delays. For example, the MTA bus was proposed for 2015.**
  - **FY17 Response: Yes there have been major delays in installing the infrastructure due to a variety of challenges including contracting the work – state procurement system, bidders protest, bids 50% higher than estimated requiring the search for additional funding (successful), and addressing permitting requirements such as the lack of a fire hydrant system. This is the first installation on non federal property and is therefore under the control of the local AHJ who had no experience with hydrogen systems and the relevant codes of which there are many. The MTA bus was purposely delayed because with no hydrogen they could not be operated and we did not want them sitting idle in a harsh salt air environment.**
  - **FY16 Reviewer Comment: More attention to project execution barriers is needed.**
  - **FY17 Response: Some barriers such as the lack of the fire hydrant system came out of the blue, others such as code official education we addressed with hydrogen and code education provided to the code officials by Boyd Hydrogen, first responder training provided by PNNL, and providing updated NFPA-2 (2016) standards.**



# 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, Significant Cost Share;**
- ✓ Natural Energy Laboratory Hawaii Authority: **Host Site; Site Work, Cost Share**
- ✓ 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, Permitting Department Workshop.**
- ✓ 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;**
- ✓ **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.**
- ✓ **Evaluate electrolyzer/BESS hybrid design**
- ✓ **Collect & analyze performance data;**
- ✓ **Prepare performance reports;**
- ✓ **Prepare peer-reviewed journal papers.**

# Technology Transfer Activities

- ✓ **Applied for a utility patent on our onboard air filtration environmental sensing system developed by HNEI for the HAVO buses operating in a high air contaminant environment.**
- ✓ **Worked closely with Powertech to develop the hydrogen scavenging system to double the delivery of hydrogen using a hydrogen transport trailer.**
- ✓ **Applied the lesson learned in this project to produce a system requirements specification for the Honolulu airport hydrogen station.**
- ✓ **Working with US DOE and HawaiiGas to develop a hydrogen FRP pipeline testing facility at NELHA that leverages the project's hydrogen infrastructure.**

# 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. Completed 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.