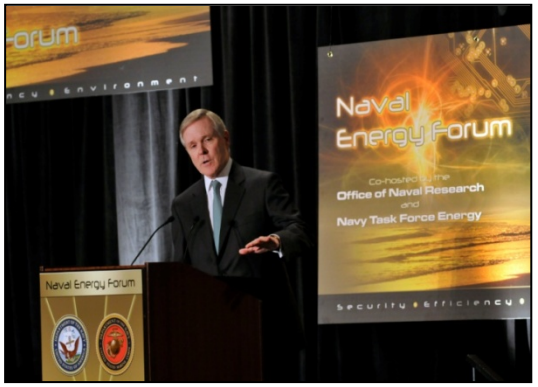
# Naval Power & Energy S&T: Hydrogen & Fuel Cells

Dr. Richard Carlin
Office of Naval Research
Department Head Sea Warfare and Weapons

Revolutionary Research . . . Relevant Results

Distribution A

# Department of the Navy (DON) Energy Goals




- **Energy Efficient Acquisition: Evaluation of energy factors will be mandatory when awarding contracts for systems and buildings.**
- **Sail the "Great Green Fleet": DON will demonstrate a Green Fleet in local operations by 2012 and sail it by 2016.**
- **Reduce Non-Tactical Petroleum Use: By 2015, DON will reduce petroleum use in the commercial fleet by 50%.**
- **Increase Alternative Energy Ashore: By 2020, DON will produce at least 50% of shore-based energy requirements from alternative sources; 50% of DON installations will be net-zero**
- **Increase Alternative Energy Use DON-Wide: By 2020, 50% of total DON energy consumption will come from alternative sources**

# Energy Systems S&T

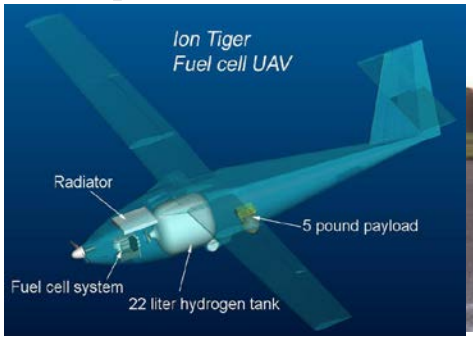
Revolutionary Research . . . Relevant Results

| | Fuel | Power Generation | Energy Storage | Distribution & Control | Power Loads |
|---|---|---|---|---|---|
| Maritime Systems | Alternative Fuels; Fuel Chemistry | Generators; Fuel Cells; GT Gen Set | | Architectures; Silicon Carbide High Power Switch; Superconducting Cable | Electric Weapons; Radars; Propellers; Hull Forms & Structures; Motors & Actuators |
| Unmanned Vehicles | Alternative Fuels; Fuel Chemistry | Fuel Cells; Engines | Batteries; Capacitors | | Sensors; Ion Tiger; USSV; Ducted Fan |
| Aircraft Systems | Alternative Fuels; Fuel Chemistry | ... Combined into a Single Versatile Propulsion System for Naval Aviation | Batteries; Capacitors | | Reconfigurable Blades/ Blade Loading; Aero Structures |
| Expeditionary Systems | Alternative Fuels; Fuel Chemistry | APU's; Engines; PV; Fuel Cells | | | |
| Shore Systems | Alternative Fuels; Fuel Chemistry | | | Grid Stabilization | |

# Unmanned Systems Power

Revolutionary Research . . . Relevant Results

## Long endurance, Unmanned Air Vehicle (UAV) power

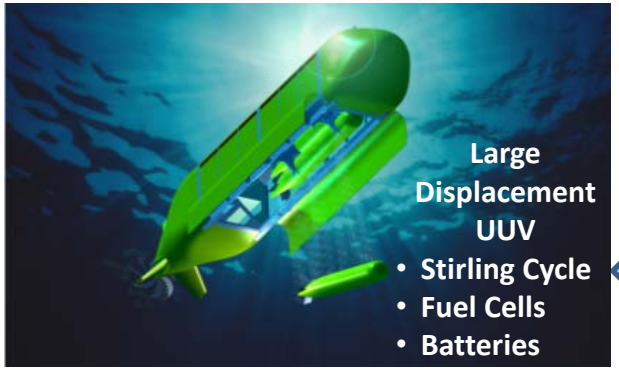



**Ion Tiger 26hr flight Nov 2009**

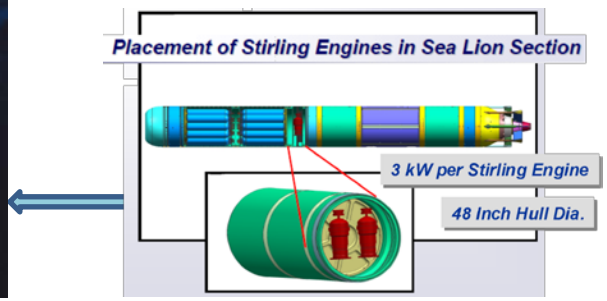
**2hr Demo flight Oct 2011**

## Long endurance, air independent Unmanned Undersea Vehicles (UUV) power systems

**Innovative Naval Prototype**




**Swampworks**



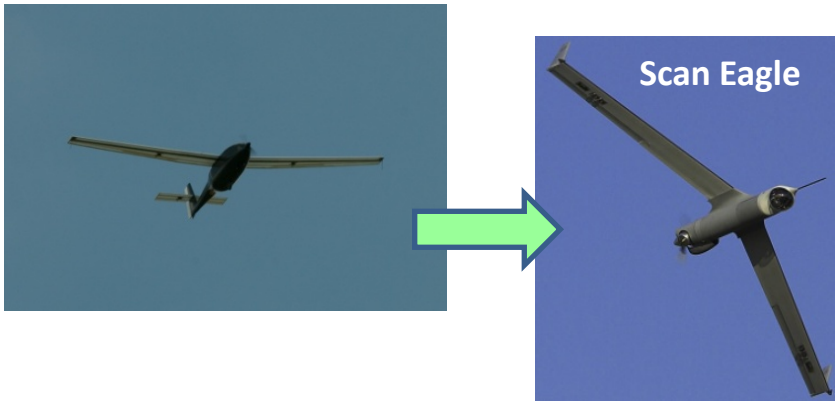

**Future Naval Capability**

# Alternative Energy Technologies
# Unmanned Air Vehicle Power Systems

Revolutionary Research . . . Relevant Results

**Adapt Ion Tiger Fuel Cell Propulsion System to Scan Eagle**

**Ion Tiger**




## Description:

- Significant interest in the Ion Tiger fuel cell UAV technology developed by NRL/ONR Code 33
- The ScanEagle vehicle demonstrator flew for for 2 hrs in October 2011
- Design work has been carried out to develop a system for up to 12 h of flight

## Approach:

- Hydrogen (polymer) fuel cell
- NRL hydrogen fuel tank technology
- NRL single stage hydrogen regulator technology
- Systems integration expertise from NRL

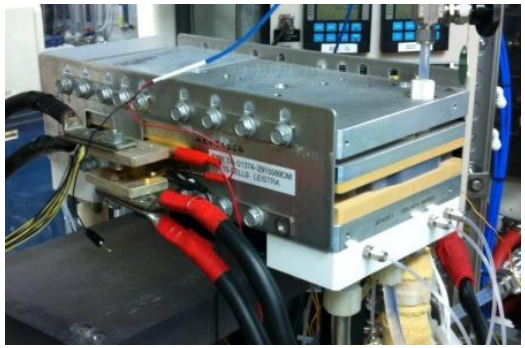
## Payoff:

- Replaces combustion engine on naval UAVs with quiet, electric fuel cell propulsion system
- Enables stealthy, low altitude flights
- Fuel cell provided better control and throttle response than engine
- Early transition of Navy-owned technology

## Characterize and optimize performance of proton exchange membrane fuel cell energy systems for use in harsh environments

- Performance and durability testing of single cells and stacks from 15 W to 5 kW with air or oxygen.
- Continuous long-term testing for performance and lifetime studies
- High resolution diagnostic tools for contaminant analysis
- High speed hardware-in-the-loop (HiL) test station to characterize fuel cell system response for UUV and UAV applications
- Custom designed impedance spectroscopy analyzer to analyze fuel cell stack and battery pack degradation mechanisms

**FC Test Facility**



**Performance testing of GM Stack for UUV**

**HiL testing for Ion Tiger**

# Expeditionary Power

Revolutionary Research . . . Relevant Results

Towable Power

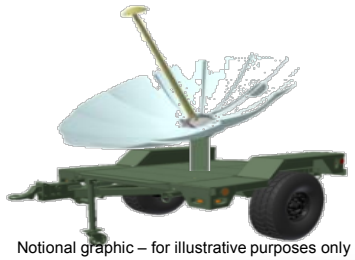
Vehicle Based APU

## Tactical Electric Power Systems

- **Modular, compact Solid Oxide Fuel Cell (SOFC) Tactical Electric Power Units will provides high efficient, silent power for towable power and vehicle-based auxiliary power units**
- **10 We SOFC Fuel Cell System – Accumetrics, UTRC**
- **Fuel: De-sulfurized JP-5 & JP-8, ULSD, and biofuels**
- **Efficiency: 37% at 50% power**
- **Power Quality: Mil Std 1332**
- **Transition for Towable Power: Army CERDEC , USMC**
- **Transition for Vehicle Based APU: Army TARDEC, AFRL**

## Renewable Sustainable Expeditionary Power (RSEP) Future Naval Capability

- **3-5kW tactical, deployable power (continuous) system capable of using a combination of conventional logistic, biofuels and solar energy**
  - **Solar concentrator**
  - **Solar-to-electric converter**
  - **Fuel-to-electric converter- *includes 3kW Acumentrics SOFC***
- **Target Metrics:**
  - **40% fuel savings over current DoD power systems**
  - **Acoustic signature 60dB(A) @ 7m**
  - **Deployable by single light tactical trailer and set-up by 2 Marines in 15 minutes**
- **Prototype testing in FY16**



Notional graphic – for illustrative purposes only

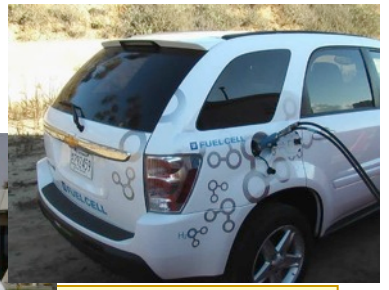
Raytheon HOMER ENERGY emcore empower with light Battelle The Business of Innovation

# Non-Tactical Ground Vehicles

## Non-tactical Hydrogen Powered General Motors Fuel Cell Vehicles and Hydrogen Infrastructure

- Evaluation ongoing at Camp Pendelton and by MARFORPAC in Hawaii
- Coordinating with other Services and DoE

MARFORPAC &
Marine Corps Base Hawaii



Marine Corps Base
Camp Pendleton

**Hawaii Advanced Vehicle Working Group (HAVWG)**

# Non-Tactical Fuel Cell Electric Vehicles (FCEVs)
## Electric Power Take-Off (EPTO)

- **FCEV Electric Power Take-off (EPTO) vehicle evaluation at Camp Pendleton**
  - 21 Months starting Feb 2013
  - 2 GM Chevrolet Equinox hydrogen fueled FCEV vehicles with EPTO capability
    - Single 90kW PEM FC
    - 4.2 kg hydrogen capacity at 700 bar
  - Electric Power Take Off (EPTO)
    - 25kW continuous / 40kW peak (min) for 5 seconds
    - 3 power outlets with circuit breakers
      - 120 Vac 60Hz single phase 20 amp
        - » Standard dual NEMA outlet with Ground Fault Circuit Interrupter
      - 120/240 Vac 60 Hz 3 wire single phase 50 amp
      - 120/240 Vac 60 Hz 3 wire single phase 125 amp
  - EPTO operation interlocked to preclude operation when vehicle is in motion
  - EPTO automatic shutdown at 20% fuel level

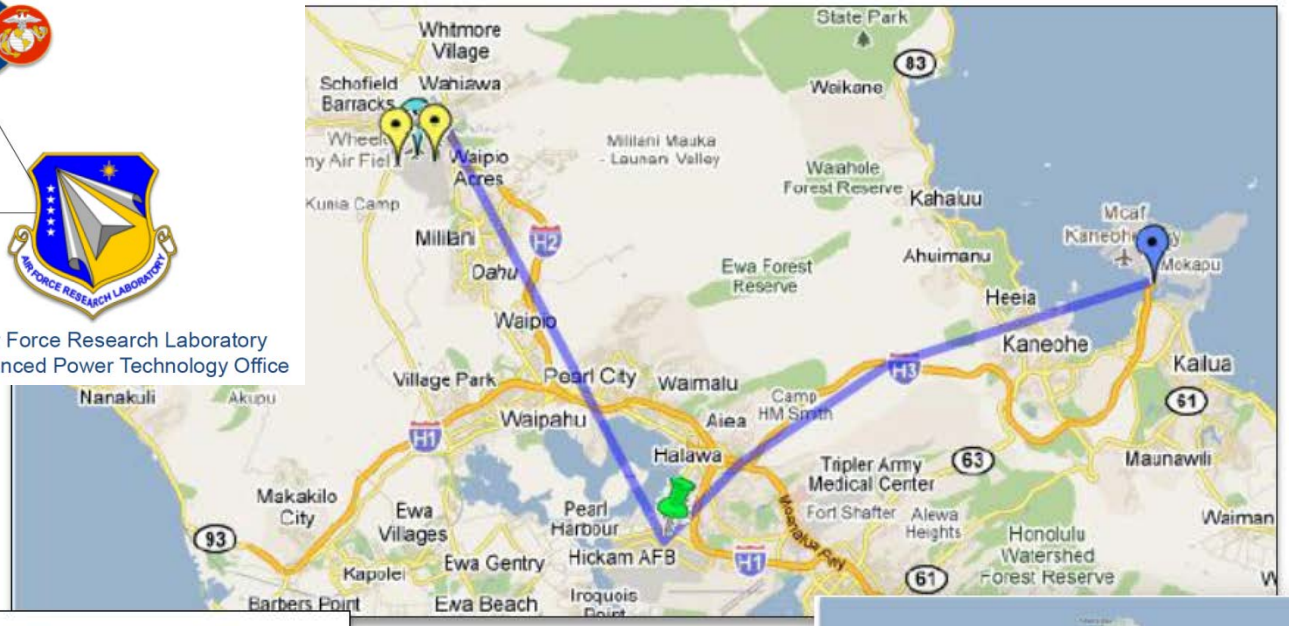
# Hawaii Advanced Vehicle Working Group (HAVWG)

Office of Naval Research

HAVWG

Tank Automotive Research, Development and Engineering Center

Air Force Research Laboratory Advanced Power Technology Office



# Joint Base Pearl Harbor-Hickam Renewable $H_2$ Production & Fueling Station

*JBPHH H2 Station Capacity Upgrades*

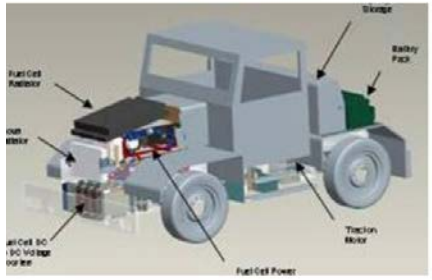
- 65 kg/day PEM Electrolyzer
- 270 kg H2 storage
- Dual compressors and dispensers for 350 bar and 700 bar refueling

TARDEC $H_2$ICE Ford Escape X 10

AF/Army/Navy GM FC Equinox X 15

DOE/Ford $H_2$ICE Bus - JBPHH

DOE/Ford $H_2$ICE Bus – Hale Koa



MB-4

Towbarless Tug with metal hydride storage

# Hydrogen Refueling Station at Marine Corps Base Hawaii

Revolutionary Research . . . Relevant Results

**Background:**

- Hydrogen refueling station to support $H_2$ powered vehicles
- All-service Hawaii Advanced Vehicle Working Group
- University of Hawaii – Hawaii Natural Energy Institute research grant

**Current Situation:**

- Temp fueling in place
- Funded and design and safety review complete
- 350 and 700 Bar equipment test in June 2013
- Initial ops planned for Aug 2013

**Future:**

- Co-locate of PV at fueling site

# DoD – DoE Fuel Cell Cooperation

## DOD-DOE MOU

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

### Enhance Energy Security MOU

The purpose of this MOU is to identify a framework for cooperation and partnership between DOE and DOD to strengthen coordination of efforts to enhance national energy security, and demonstrate Government leadership in transitioning America to a low carbon economy.

**Aviation APUs Workshop: 9/30/2010**

**Purpose:**
- To begin discussing collaboration across DOD and DOE in keeping with the MOU
- To motivate RD&D for APU applications

**Next Steps**
- Identify specific POCs for DOD activities (RED DOTS)
- Develop GSE Strategic Demo Plan

**Waste-to-Energy Workshop: 1/13/2011**

**Purpose:**
- To identify DOD-DOE waste-to-energy and fuel cells opportunities
- To identify challenge and determine actions to address them

**Next Steps**
- Set up an on-going WG to begin coordination, collaboration, assistance
- Develop a guidance document for Feds using third party financing

**Shipboard APUs Workshop: 3/29/2011**
- March 2011
- Organized by ONR

1 | Fuel Cell Technologies Program Source: US DOE 2/16/11 eere.energy.gov

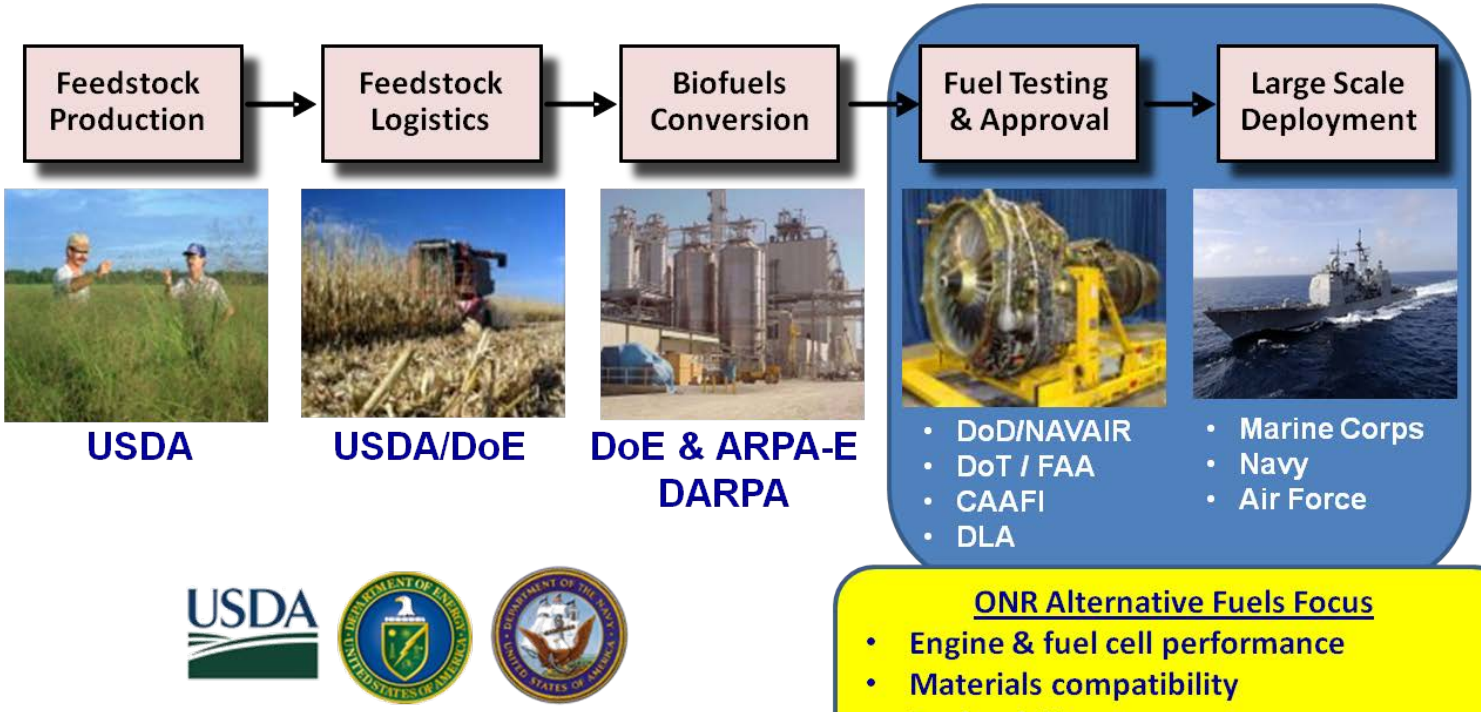
Source: http://www1.eere.energy.gov/hydrogenandfuelcells/wkshp_proceedings.html under "Market Transformation"

# Collaborative Biofuels Research

Revolutionary Research . . . Relevant Results

***ONR Objectives:*** **Accelerate the adoption of biofuels by supporting Navy certification process, and understand & mitigate the impact of emerging biofuels on naval power systems & operations**

## *Biofuels Supply Chain*




**ONR Alternative Fuels Focus**

- Engine & fuel cell performance
- Materials compatibility
- Fuel stability
- Sustainable biomass production models

# Fuel-Efficient Shipboard Fuel Cells

Revolutionary Research . . . Relevant Results

Shipboard Fuel Cell System Concept

Previous evaluations

600kW 1st Gen Fuel Cell System

High Density Reforming

10kW Solid Oxide Fuel Cell APU

## Status:

- SBIR to demonstrate innovative Biofuel reforming process 10kW and greater SOFC systems
- Award planned in May 2013

## S&T Focus:

- Improved fuel cell system efficiency to > 40%
- Volumetric Density > 25 watts/liter
- Modular, Scalable from 10kW to > 100kW
- Thermally integrated reformer/stack

## Technical Challenges:

- ***Improving reformer efficiencies with biofuels***
- Improving thermal management methods for reformer/stack operation
- Improving membranes and materials

## Technical Approach:

- Develop and validate process models
- ***Develop biofuel reformer and validate operation with existing 10kW SOFC units***
- Scale-up to ship relevant size
- Demonstrate and validate fuel cell stack characteristics in the Navy environment

# Purification of Landfill Biogas for Fuel Cells SBIR Phase I & II

Revolutionary Research . . . Relevant Results

- **Objective:** Develop and demonstrate innovative, compact and no maintenance Waste to Energy system generating fuel cell electrical power from biogas
- **Challenge:** Efficient removal of impurities form the gasses for downstream use by fuel cells

| Composition | Natural Gas | Biogases | | | |
|---|---|---|---|---|---|
| | | Waste Water | Food Waste | Animal Waste | Landfill |
| Methane (Vol%) | 80 – 100 | ~50 – 60 | ~50 – 70 | 45 – 60 | 40 – 55 |
| Carbon Dioxide (Vol%) | <3 | 30 – 40 | 25 – 45 | 35 – 50 | 35 – 50 |
| Nitrogen (Vol%) | <3 | <4 | <4 | <4 | <20 |
| Oxygen (Vol%) | <0.2 | <1 | <1 | <1 | <2 |
| $H_2S$, ppm | <0.1 | <400 | <10,000 | <300 | <200 |
| Non-$H_2S$ Sulfur, ppm | <10 | <1 | <1,000 | <30 | <30 |
| Halogens, ppm | <0.1 | <0.2 | <0.2 | <0.2 | <100 |
| Moisture, % | <0.02 | ~3 | ~3 | ~3 | ~3 |

*Source: Frank Wolak, "Fuel Cell Power Plants: Biofuel Case Study – Tulare, CA," Biogas and Fuel Cells Workshop, Golden, CO, June 11–13, 2012, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/june2012_biogas_workshop_wolak.pdf*

**Impurity Levels in Waste Streams**

| Type of Fuel Cell | PAFC | MCFC | SOFC |
|---|---|---|---|
| $H_2S$ | 2.0 | 0.1 – 5.0 | 1.0 |
| COS, $CS_2$, mercaptan | | 1.0 | |
| Organic sulfur | | 6.0 | |
| $H_2S$, COS, $CS_2$ | | 0.5 – 10.0 | |
| HCl, ppm | | 0.1 | "few" |
| Halogens | 4.0 | 0.1 – 1.0 | 1.0 – 5.0 |
| Halogenated organics | | 0.1 | |
| $NH_3$ | 1.0 | 10,000 | 5,000 |
| Siloxanes | | 1.0 | 0.01 |
| Tars | | 2,000 | |

*Source: Shabbir Ahmed, "Biogas Impurities and Cleanup for Fuel Cells," Biogas and Fuel Cells Workshop, Golden, CO, June 11–13, 2012*

**Impurity Levels for Longevity of FC's**

- Phase I completing and Phase II starting
- Two small businesses
  - Reactive Innovation, LLC
  - Lynntech, Inc

# Micro Solid Waste Gasification Systems for Thailand

Revolutionary Research . . . Relevant Results

## S&T Research Goals

Primary research goals:

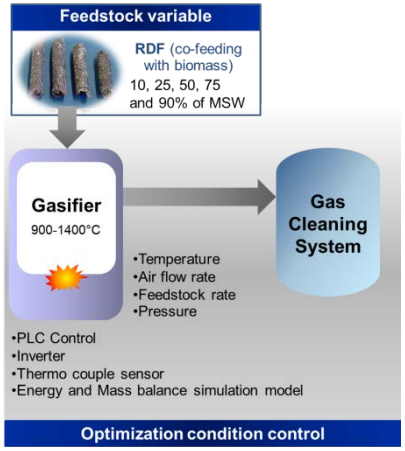
- Investigate the type and quality of co-feedstock in relationship to efficiency of the gasification system in order to investigate sustainable feedstock pre-treatment system.
- Develop an energy and mass balance model for an Municipal Solid Waste (MSW) gasification system that can be applied to Local Government Authorities.

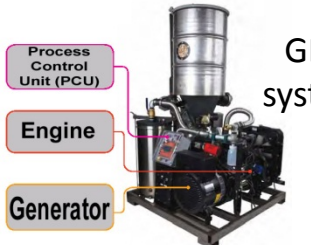
Secondary research goals:

- Air pollution analysis on gasifier discharge
- Char/ash analysis
- Gasifier Experimenter's Kit (GEK) from *All Power Lab* for Reliability, Maintainability & Availability (RMA) Analysis

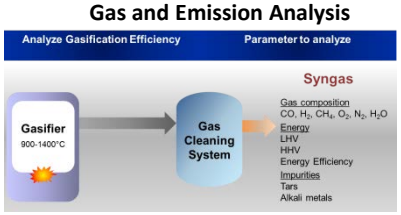
http://www.gekgasifier.com

Refuse Derived Fuel (RDF) & GEK system technology evaluation




GEK system




## Participants

- Grant Country: Thailand
- ONR/NRL Program Manager: Dr. Richard Carlin (ONR, Code 33)
- International Researcher: Assoc. Prof. Dr. Wattanapong Rakwichian University of Phayao
- US Collaboration: Dr. Richard Carlin (ONR 33)
- ONRG Associate Director: CAPT Paul Marshall
- Budget: $182K FY13/14 ($110K US)

# Anaerobic Digestion for Dilute Waste Streams

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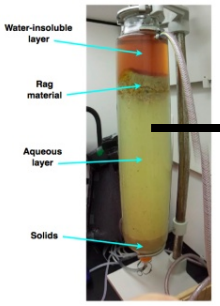
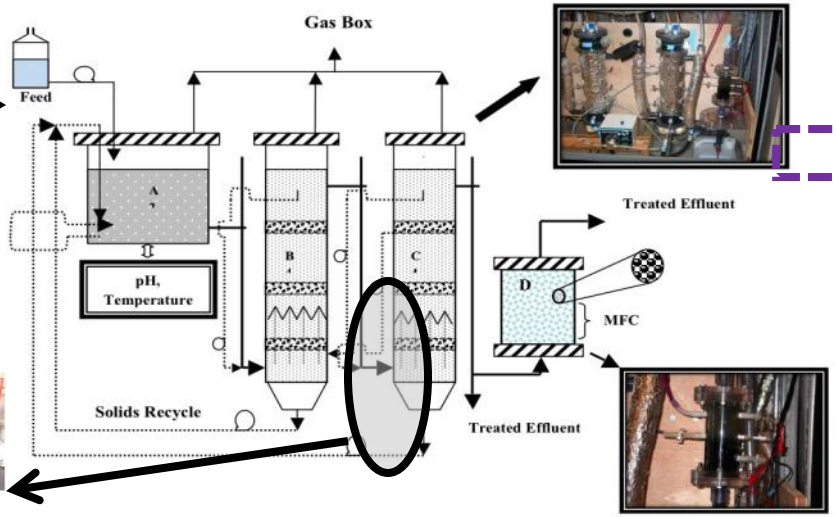


Hawaii Natural Energy Institute
University of Hawaii at Manoa

**Ten (10) liter lab high-rate anaerobic digester for evaluation of packing materials and operating conditions (e.g. hydraulic retention time and packing density)**

**Five thousand (5000) liter demonstration at local waste water treatment facility to reduce BOD of primary effluent (operating)**

**One thousand (1000) liter demonstration at local grease-trap waste facility (under development)**

# Sustainable Energy Infrastructure

Revolutionary Research . . . Relevant Results

***Hawaii as the Defense Energy Model for Asia-Pacific Region***

- ***Increase penetration of renewable energy into DoD installations and partner communities***
- ***Distributed power for Humanitarian Assistance & Disaster Relief (HADR), Expeditionary Ops, and FOBs***

Energy Storage

Optional Grid Connection

Fuel Cell UAV

Solar PV

Wind

Smart Grid Interface

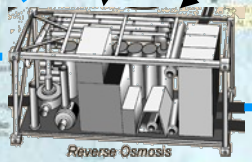
Electric or Fuel Cell Vehicles

FROG ZERO Hawaii Project

Fuel Cell / Electrolyzer

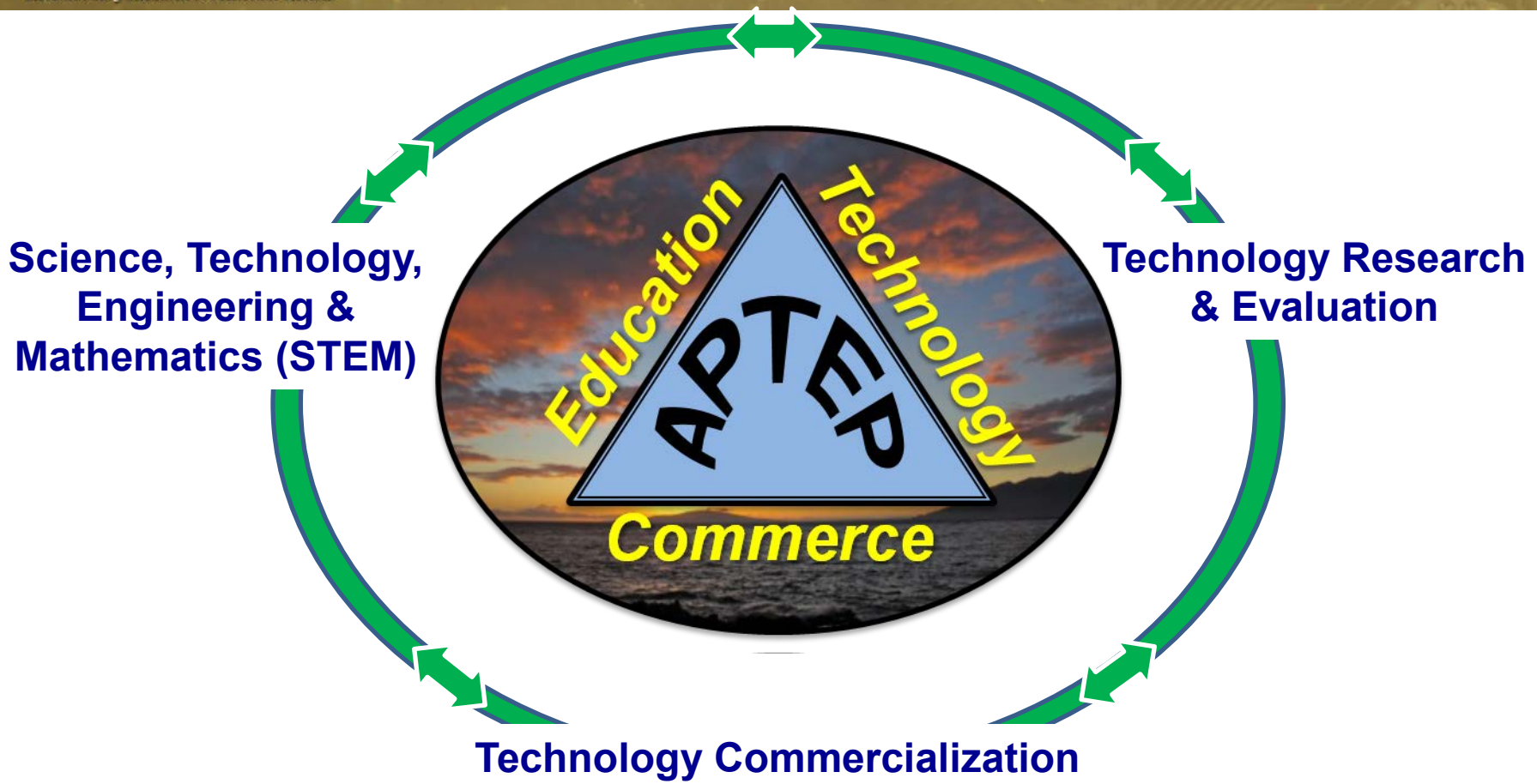
Fuel Cell UGV ISR / Sentry

FROG ZERO Hawaii Project




Reverse Osmosis Water Unit

# Asia Pacific Technology & Education Program [APTEP]



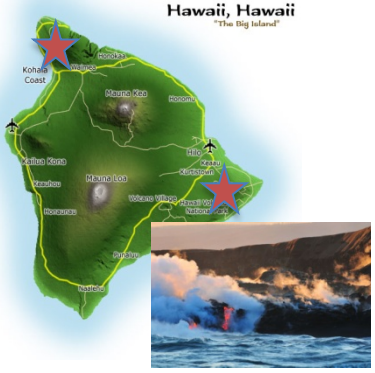

- Promote sustainability through alternative energy research, technology development & education
- Provide a CleanTech workforce by linking energy education & research institutes with CleanTech companies

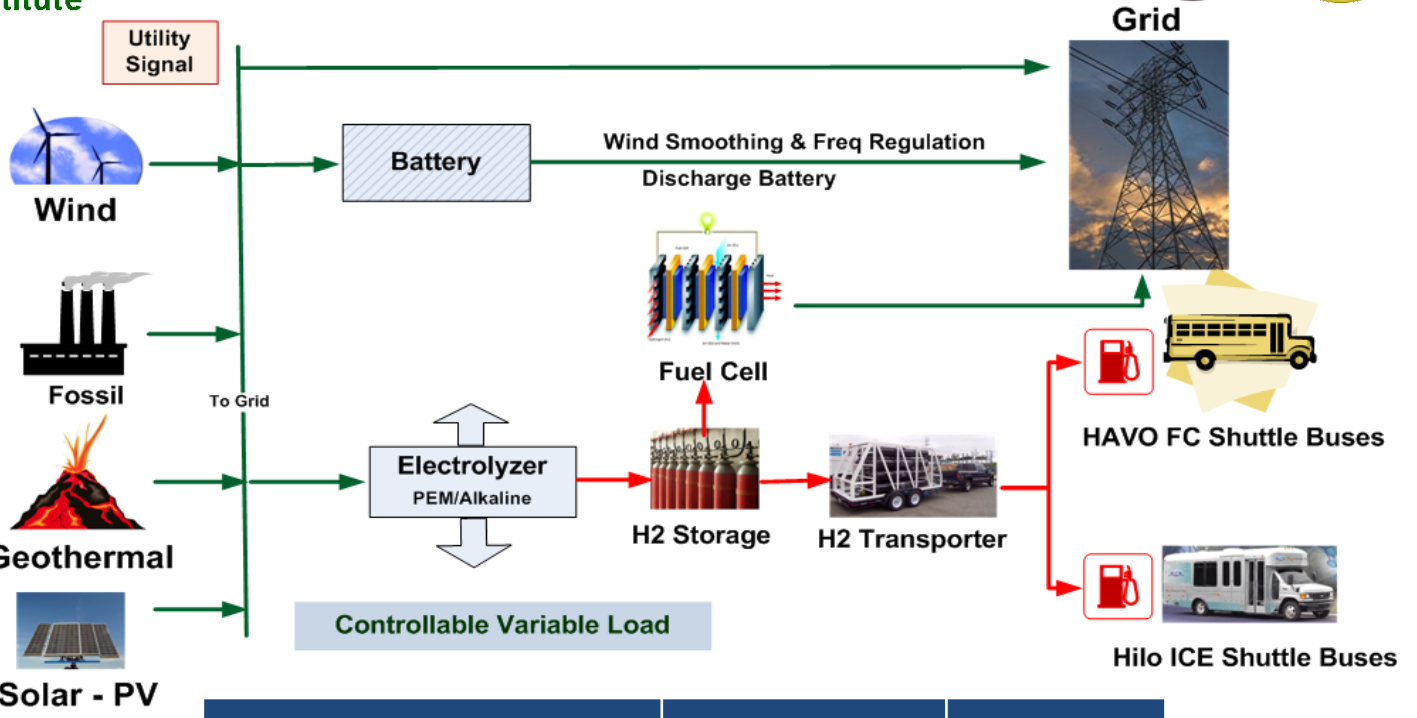
# Batteries & Electrolyzers as Grid Management Tools

Revolutionary Research . . . Relevant Results

Hawaii Natural Energy Institute
University of Hawaii at Manoa

Hawaii, Hawaii






*Electrolyzers can serve as dynamic load to mitigate intermittency*

*Degradation is potential issues for electrolyzers and battery storage*

| Service | Electrolyzer | Battery |
|---|---|---|
| Up Reserve | Yes | Yes |
| Down Reserve | Yes | Yes |
| Up Regulation | Yes | Yes |
| Down Regulation | Yes | Yes |
| Fuel Production | Yes | No |
| Voltage/VAR Support | No | Yes |

# Battery Energy Storage for Grid Management

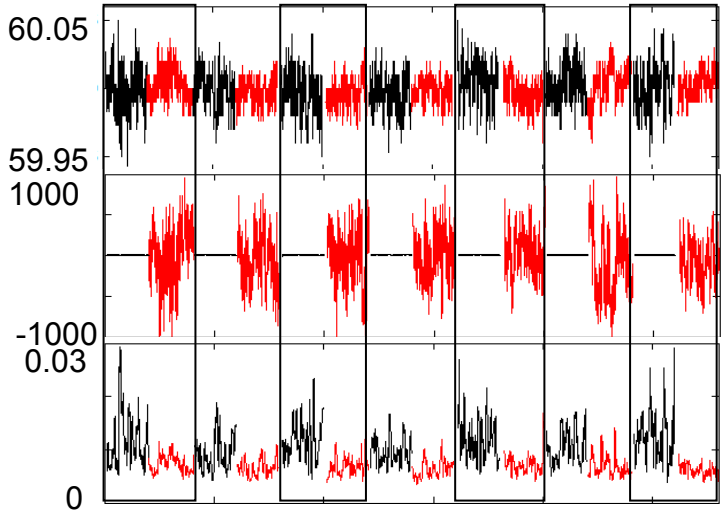
Hawaii Natural Energy Institute
University of Hawaii at Manoa

Haw'i Wind Farm

BESS at Haw'i wind farm

**Demonstrate use of fast battery energy storage to manage frequency variability caused by intermittent renewable generation**

- **1 MW, 250 kW-hr Lithium-ion Titanate BESS from Altairnano installed on HELCO grid at interface between wind farm/utility**
- **Algorithms developed to manage frequency response and state of charge of battery**
- **Grid response (frequency) measured with battery on and battery off**
- **Grid and battery characteristics continuously monitored**




**Grid frequency(Hz):** measured with battery off (black) and on (red) at twenty(20) minute intervals

**Battery output(kW);** can alternate between charge and discharge up to 10 times per second

**Standard Deviation:** Local STD provides quantitative measure of impact of battery on frequency. Frequency variability reduced up to 40% with battery

**Enabling the integration of high-penetration of renewable energy generation into micro-grid systems**

# MEDB & Chaminade University

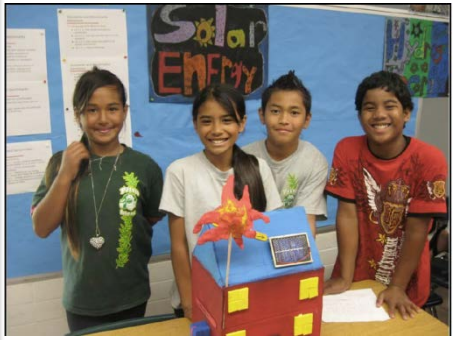
## Maui Economic Development Board (MEDB)

ONR Co-Funding Island Energy Inquiry

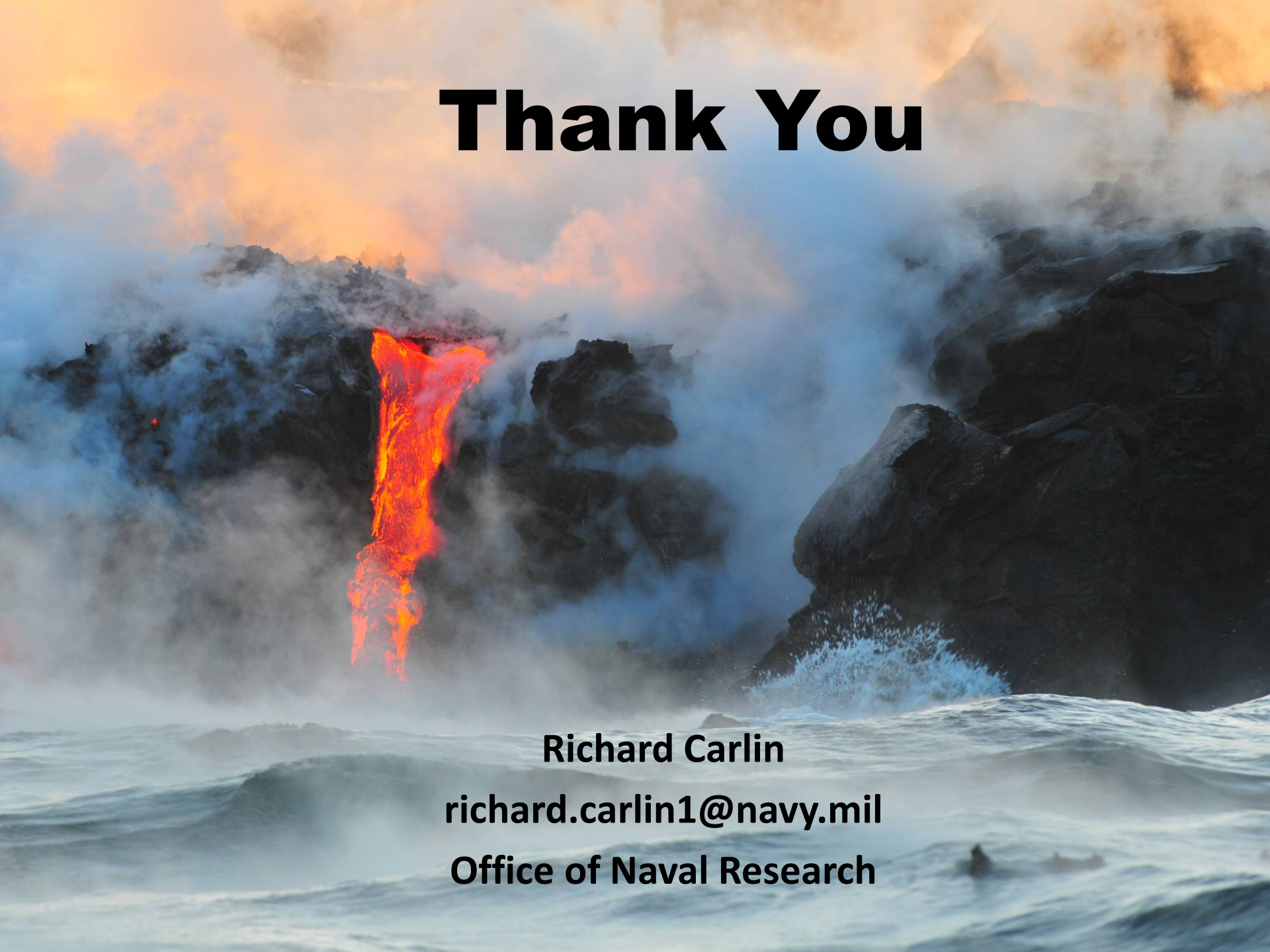
medb
maui economic development board, inc.

## Chaminade University

### TECHNOLOGY ENHANCED SUSTAINABLE AINA PROJECT IMPLEMENTING ENGINEERING DESIGN PRINCIPLES IN HAWAI'I ELEMENTARY SCHOOLS




| Kula Kaiapuni `o Ānuenue | Palolo Elementary |
|---|---|
| Hawaiian Language Immersion School | Public Hawaii DOE School |
| High population Hawaiian (94% all or part Hawaiian) | High population Pacific Islander (84% all or part Pacific Islander including Hawaiian) |
| High proportion of students received free or reduced price lunch (58% Ānuenue, 90% Palolo) | |



# Thank You

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**Office of Naval Research**