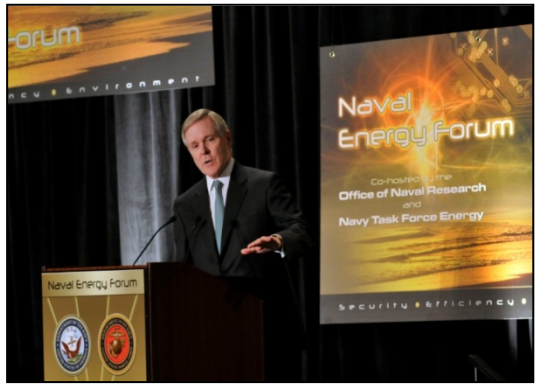
Naval Power & Energy S&T: Hydrogen & Fuel Cells

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

Revolutionary Research . . . Relevant Results

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**

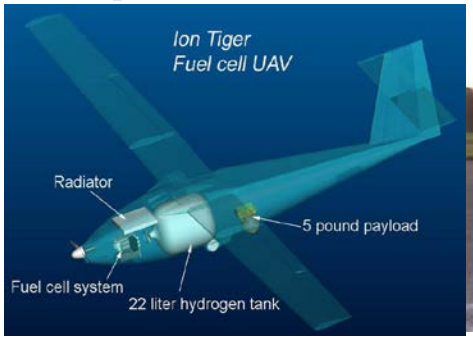
Energy Systems S&T

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

Long endurance, Unmanned Air Vehicle (UAV) power

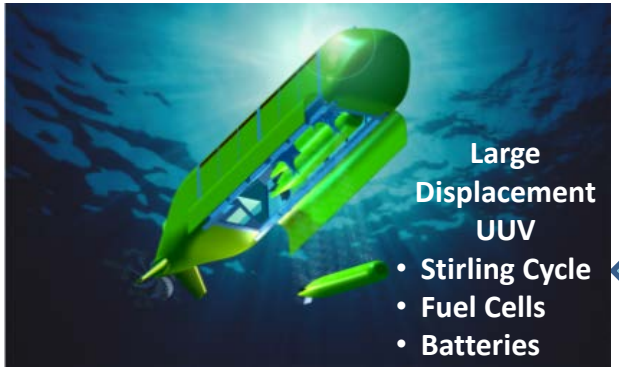


Ion Tiger 26hr flight Nov 2009

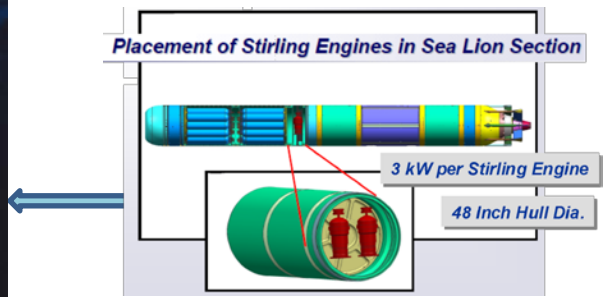
2hr Demo flight Oct 2011

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

Innovative Naval Prototype



Swampworks



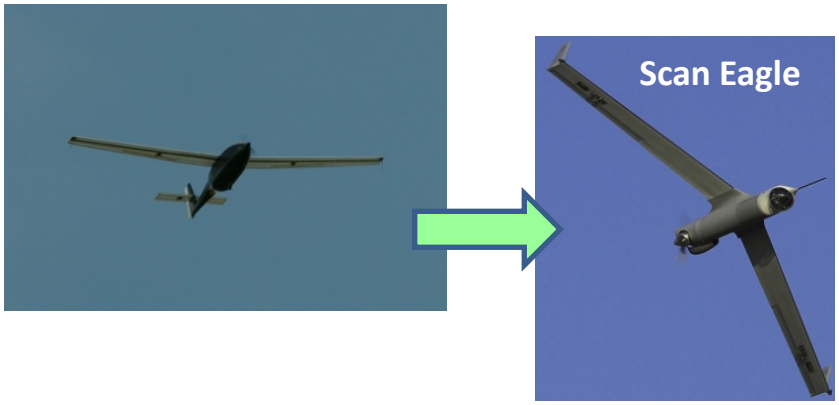
Future Naval Capability

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

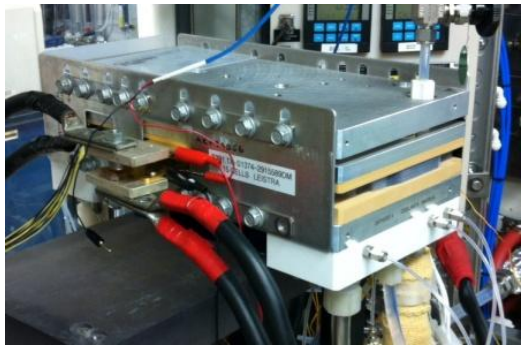
Payoff:

- 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

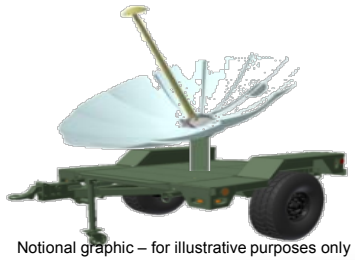
Vehicle Based APU

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

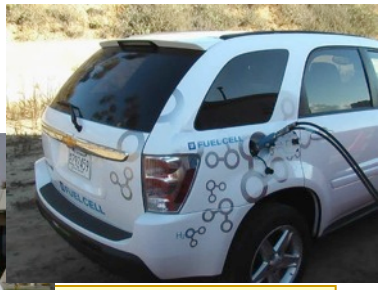
Battelle The Business of Innovation

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)

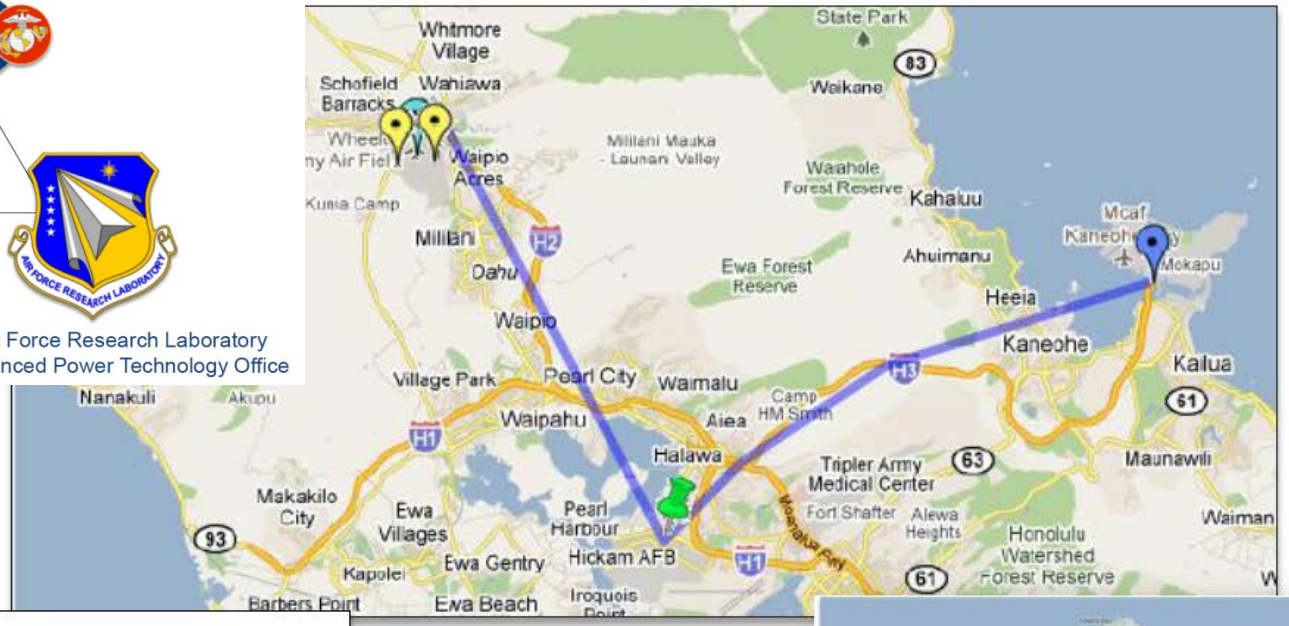
Office of Naval Research

HAVWG

TARDEC

Tank Automotive Research, Development and Engineering Center

Air Force Research Laboratory Advanced Power Technology Office



- APTO H2 Station
- Proposed H2 Station-TARDEC
- Proposed H2 Station-ONR
- TARDEC Microgrid #1
- TARDEC Microgrid #2

HCATT

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

JBPHH H2 Station Capacity Upgrades

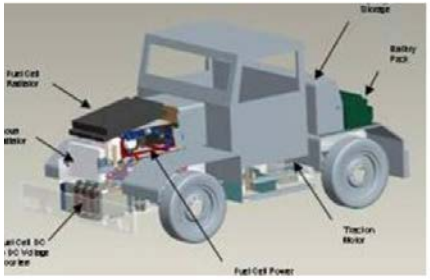
- 65 kg/day PEM Electrolyzer
- 270 kg H2 storage
- Dual compressors and dispensers for 350 bar and 700 bar refueling

TARDEC H_2ICE Ford Escape X 10

AF/Army/Navy GM FC Equinox X 15

DOE/Ford H_2ICE Bus - JBPHH

DOE/Ford H_2ICE 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

Feedstock Production	Feedstock Logistics	Biofuels Conversion	Fuel Testing & Approval	Large Scale Deployment
				
USDA	USDA/DoE	DoE & ARPA-E DARPA	• DoD/NAVAIR • DoT / FAA • CAAFI • DLA	• Marine Corps • Navy • Air Force

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:

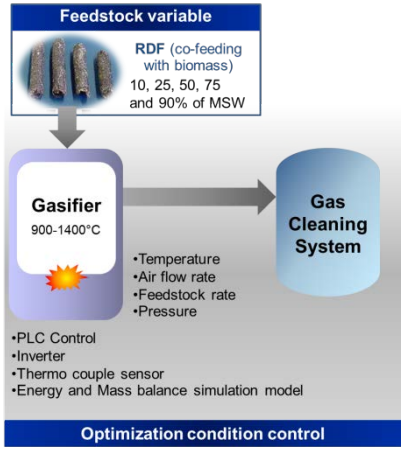
- Investigate the type and quality of co-feedstock in relationship to efficiency of the gasification system in order to investigate sustainable feedstock pre-treatment system.
- Develop an energy and mass balance model for an Municipal Solid Waste (MSW) gasification system that can be applied to Local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

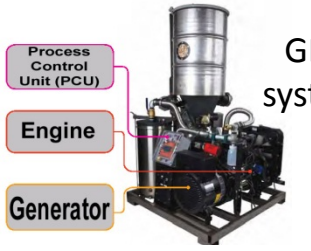
Secondary research goals:

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

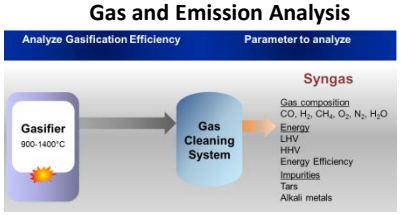
http://www.gekgasifier.com

Refuse Derived Fuel (RDF) & GEK system technology evaluation





GEK system

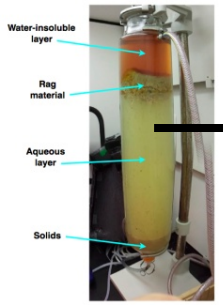


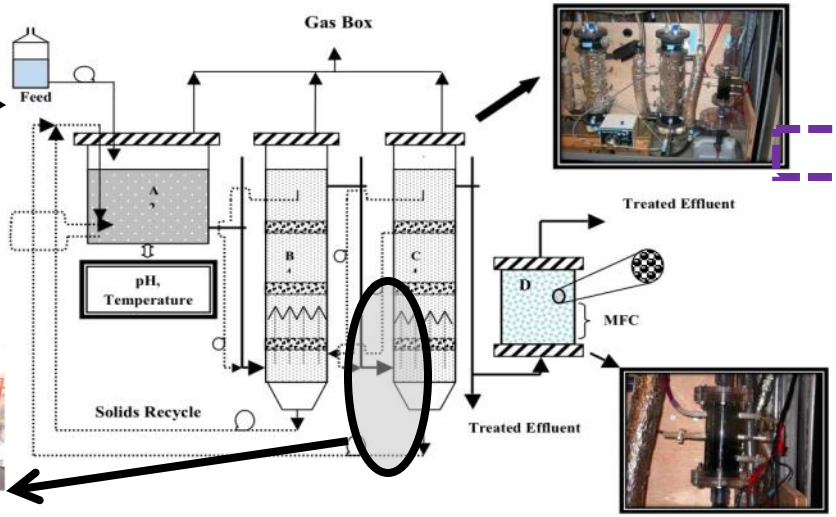
Participants

- 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

Revolutionary Research . . . Relevant Results





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

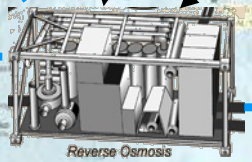
Electric or Fuel Cell Vehicles

FROG ZERO Hawaii Project

Fuel Cell / Electrolyzer

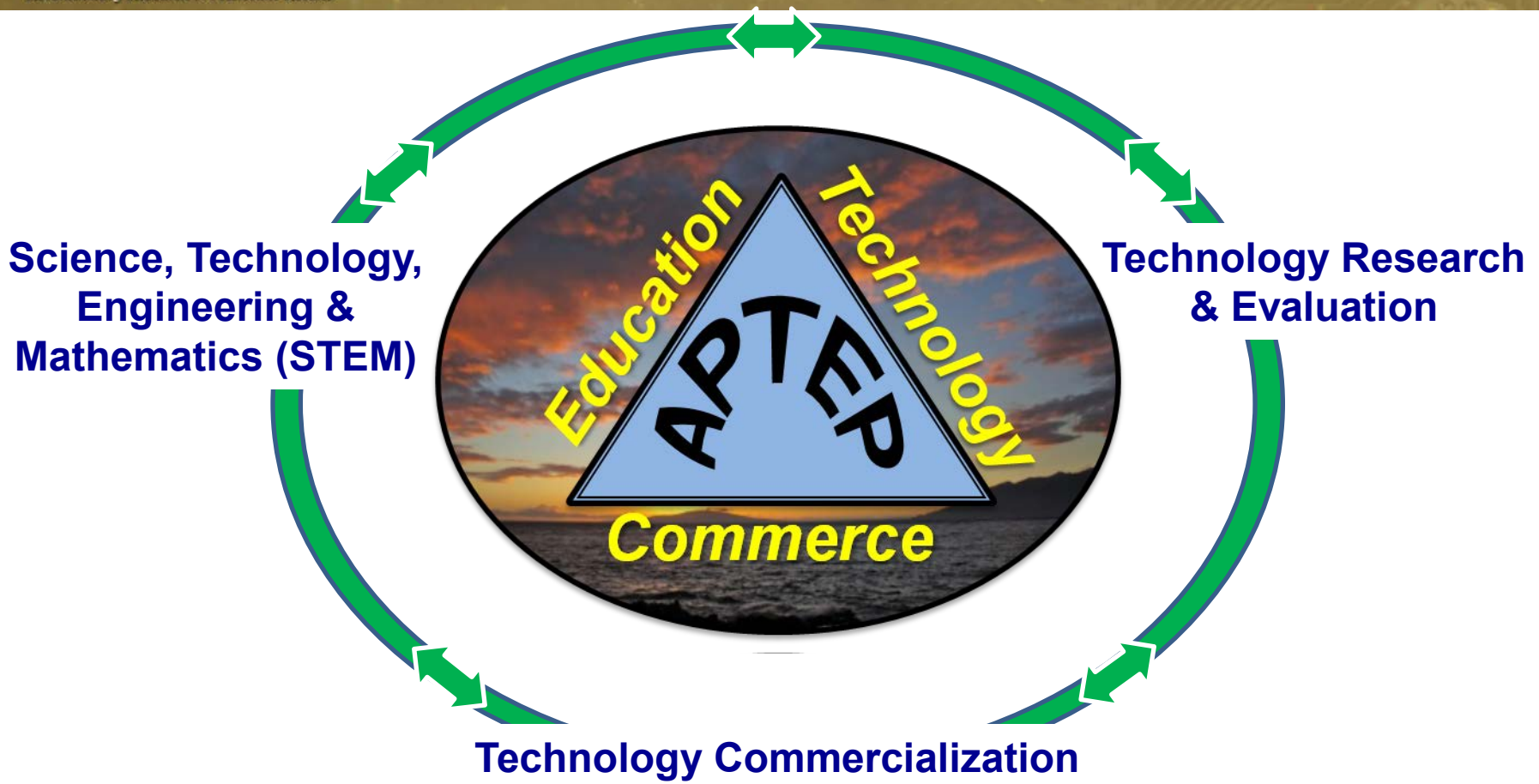
Fuel Cell UGV ISR / Sentry

FROG ZERO Hawaii Project



Reverse Osmosis Water Unit

Asia Pacific Technology & Education Program [APTEP]



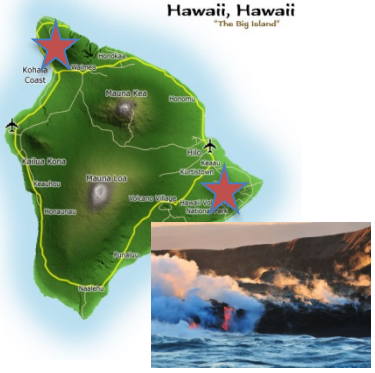
- Promote sustainability through alternative energy research, technology development & education
- Provide a CleanTech workforce by linking energy education & research institutes with CleanTech companies

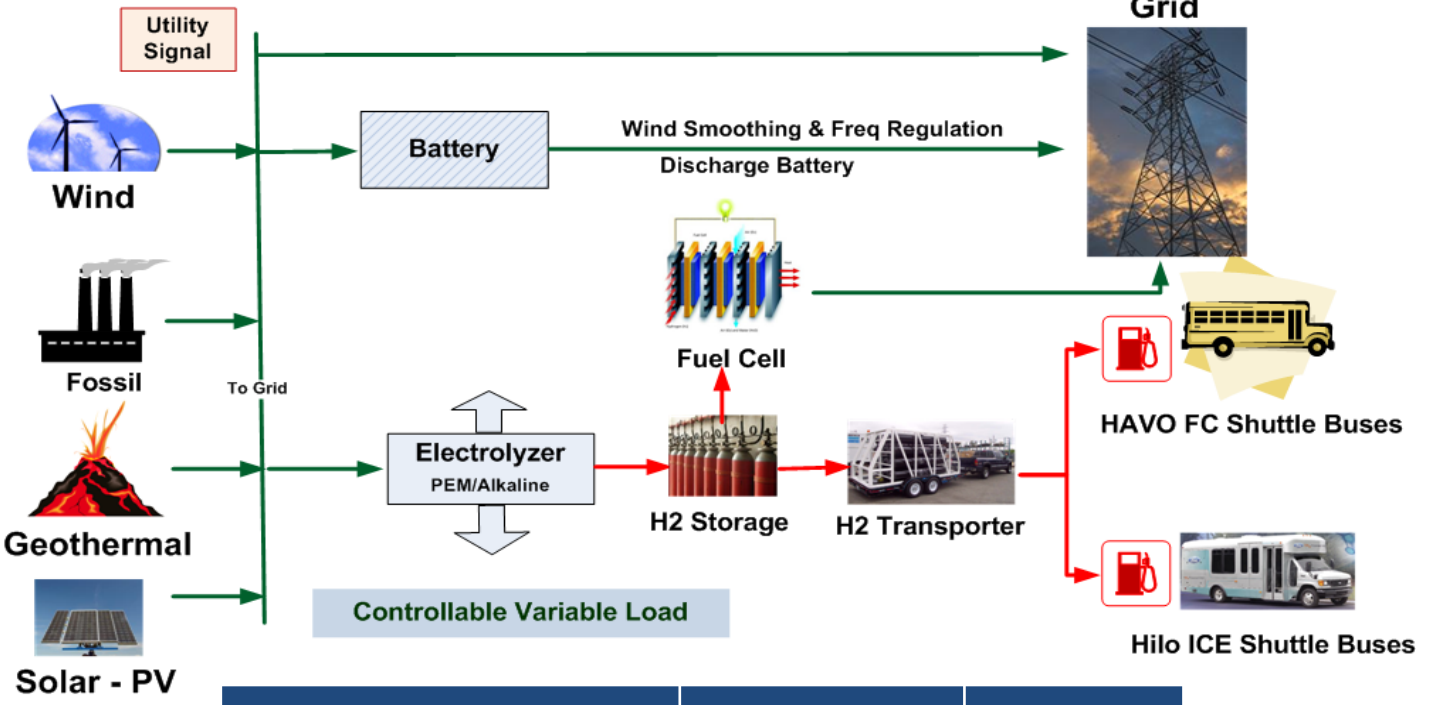
Batteries & Electrolyzers as Grid Management Tools

Revolutionary Research . . . Relevant Results

Hawaii Natural Energy Institute
University of Hawaii at Manoa

Hawaii, Hawaii
"The Big Island"





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

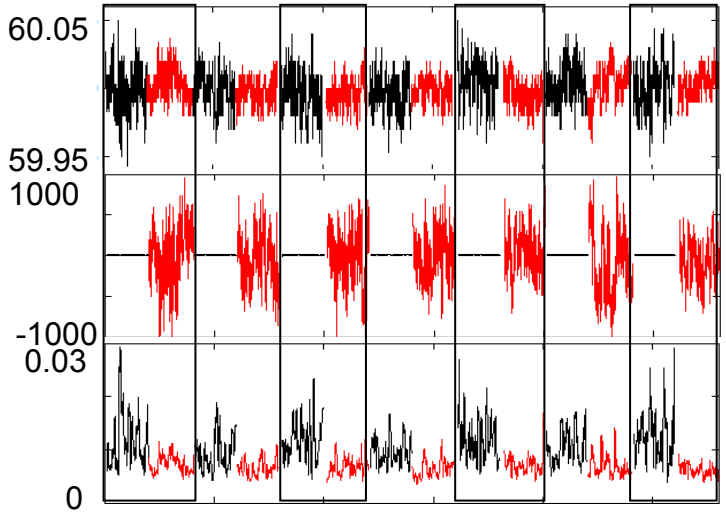
Hawaii Natural Energy Institute
University of Hawaii at Manoa

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

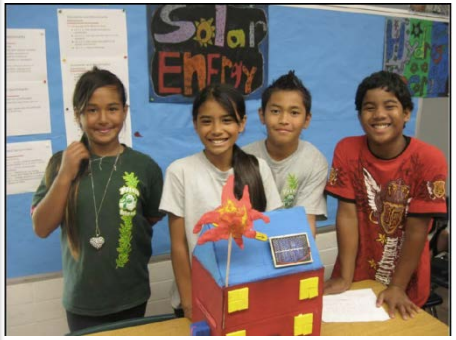
Maui Economic Development Board (MEDB)

ONR Co-Funding Island Energy Inquiry

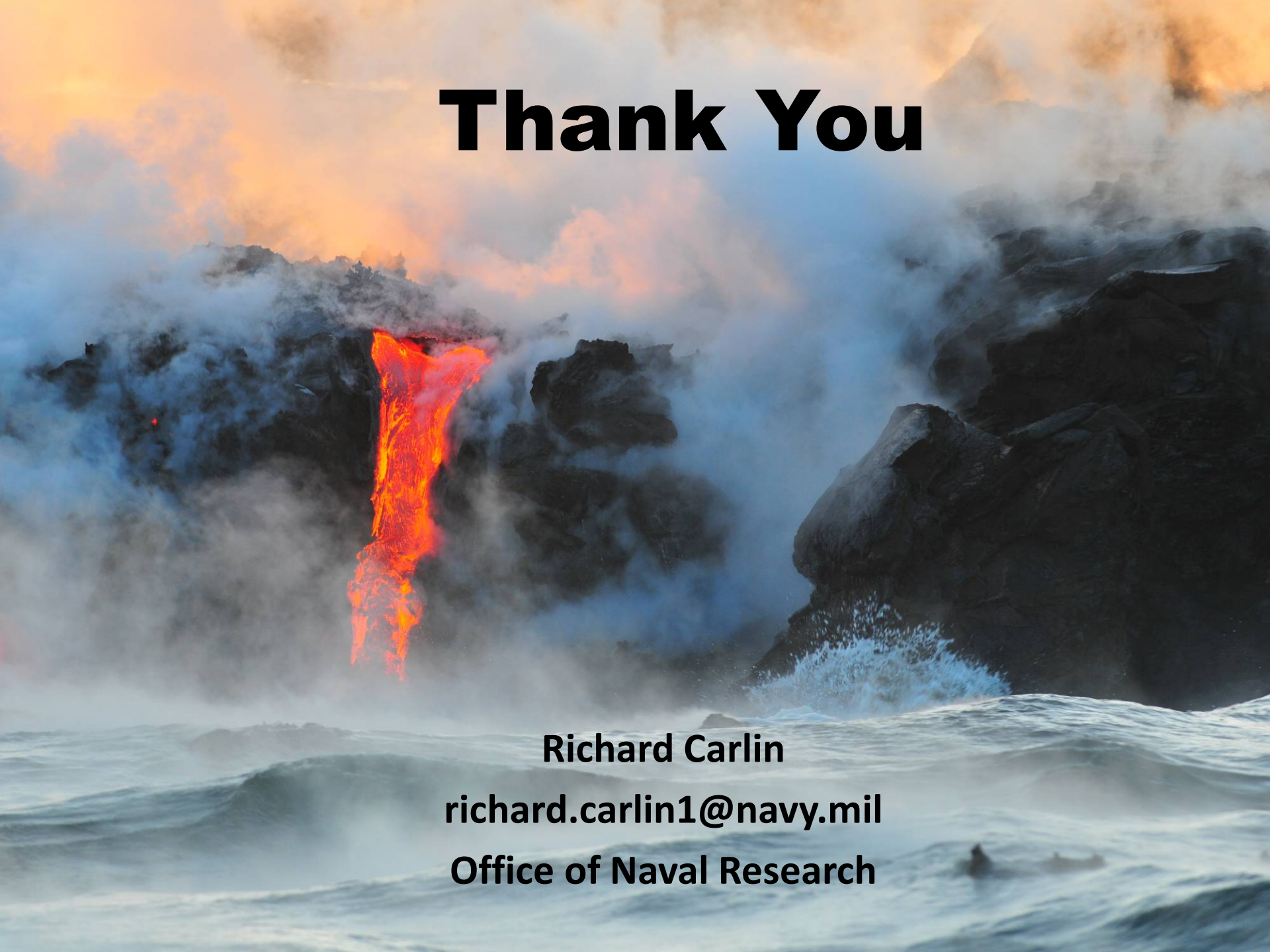
medb
maui economic development board, inc.

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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