Brief to
Hydrogen Technology Advisory Group

DoD R&D Update

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Hydrogen and Fuel Cell R&D Programs

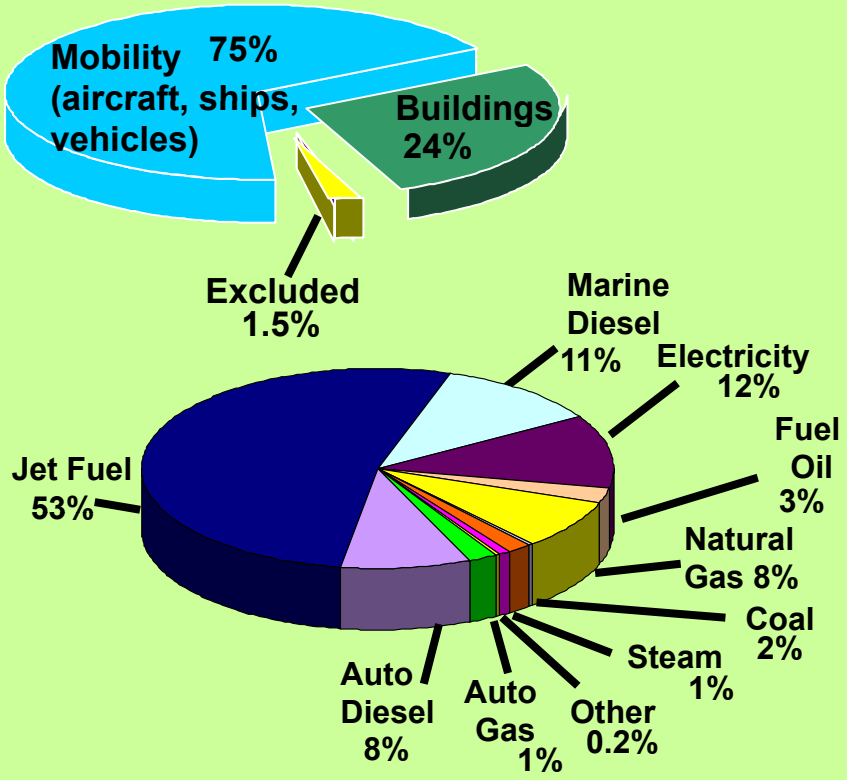
Goals:

- Be an ***early adopter*** and ***principal demonstrator***
- Foster competition in the marketplace and provide a market demand
- Support improved Technology and Manufacturing Readiness Levels
  - Exercise the supply chain
  - Test under real world conditions
  - Provide feedback to manufacturers

- Improve fuel cell readiness by funding R&D efforts in areas that are near commercialization
- Support DoD-unique research to leverage other government and commercial R&D investments

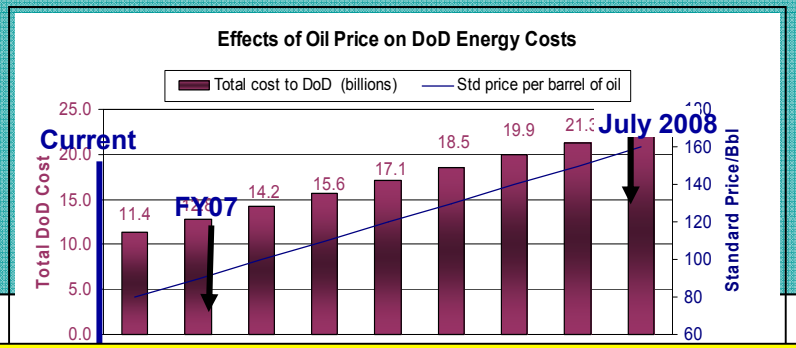
DoD Energy Use and Cost

DoD FY07 Consumption (by BTUs)



Cost

- DoD spent over $13B on energy in FY07
- FY09 PresBud built with standard price at $115/Bbl; Current price: ~$40/Bbl **
- DoD cost to users (standard price) is roughly $30 / barrel above world spot price (refining / distribution)
- $10 per barrel increase in oil increases DoD costs by ~$1.3B per year
- Current costs provide a multi-billion dollar problem for each year in FYDP

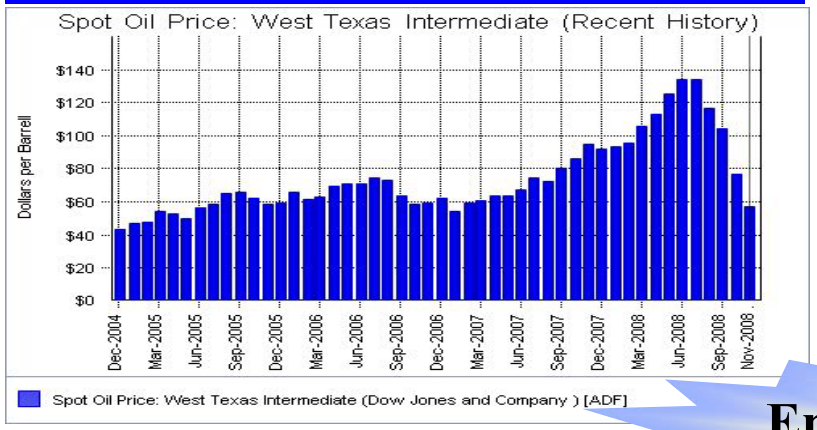


COST PAYOFF: Reduced energy use for mobility, fixed and tactical installations
OPERATIONAL PAYOFF: Fewer refuelings; increased platform availability
Both support enhanced energy focus and free up resources to apply elsewhere

** **Note:** DoD Standard Price Includes ~$30/Bbl for refining / distribution. FY09 price reduced to $69.72 as of 2-1-09.

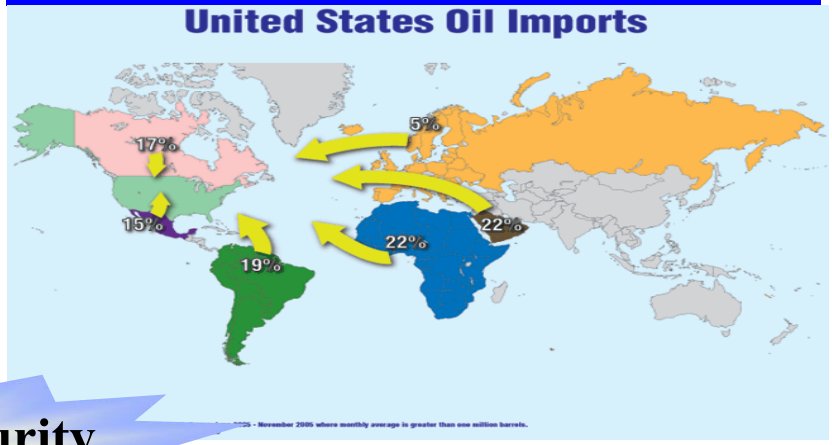
DoD Energy Security Drivers

Price Volatility Impacts Other Programs



US Oil Sources May Not Be Stable

Source: EIA, Period Aug 07- JaN 08



Energy Security Drivers

Logistics of Moving Fuel Can Limit Combat OPS

Modern Military Systems Use of Energy Increasing

DoD Energy Security Drivers
--Wild Cards--

Influence from Global Suppliers

Price of oil bounces off four-year lows

OPEC president suggests large production cut on the way

AP Associated Press December 8, 2008 @ 1700

Oil prices rebounded from four-year lows and shot above $43 a barrel Monday as OPEC floated the possibility of a "severe" production cut and several countries announced new measures to boost their economies…

Russia wields the energy weapon

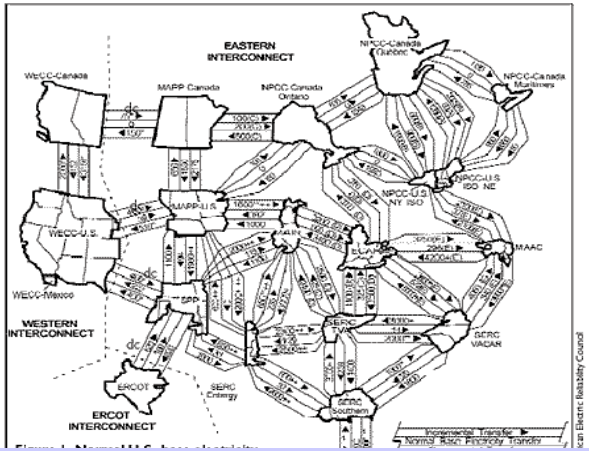
BBC News, Moscow, February 14, 2006

When Russia turned off the gas to Ukraine, it sent shivers across Europe where customers are increasingly dependent on Russia to keep warm.

Energy as a Strategic "Weapon"

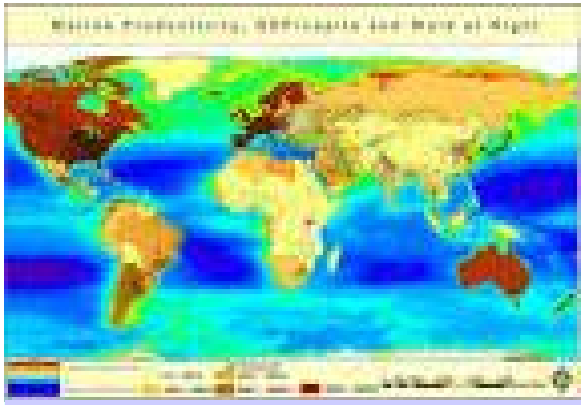
Humanitarian Relief

Energy Security Drivers



Grid Vulnerability

Future Systems



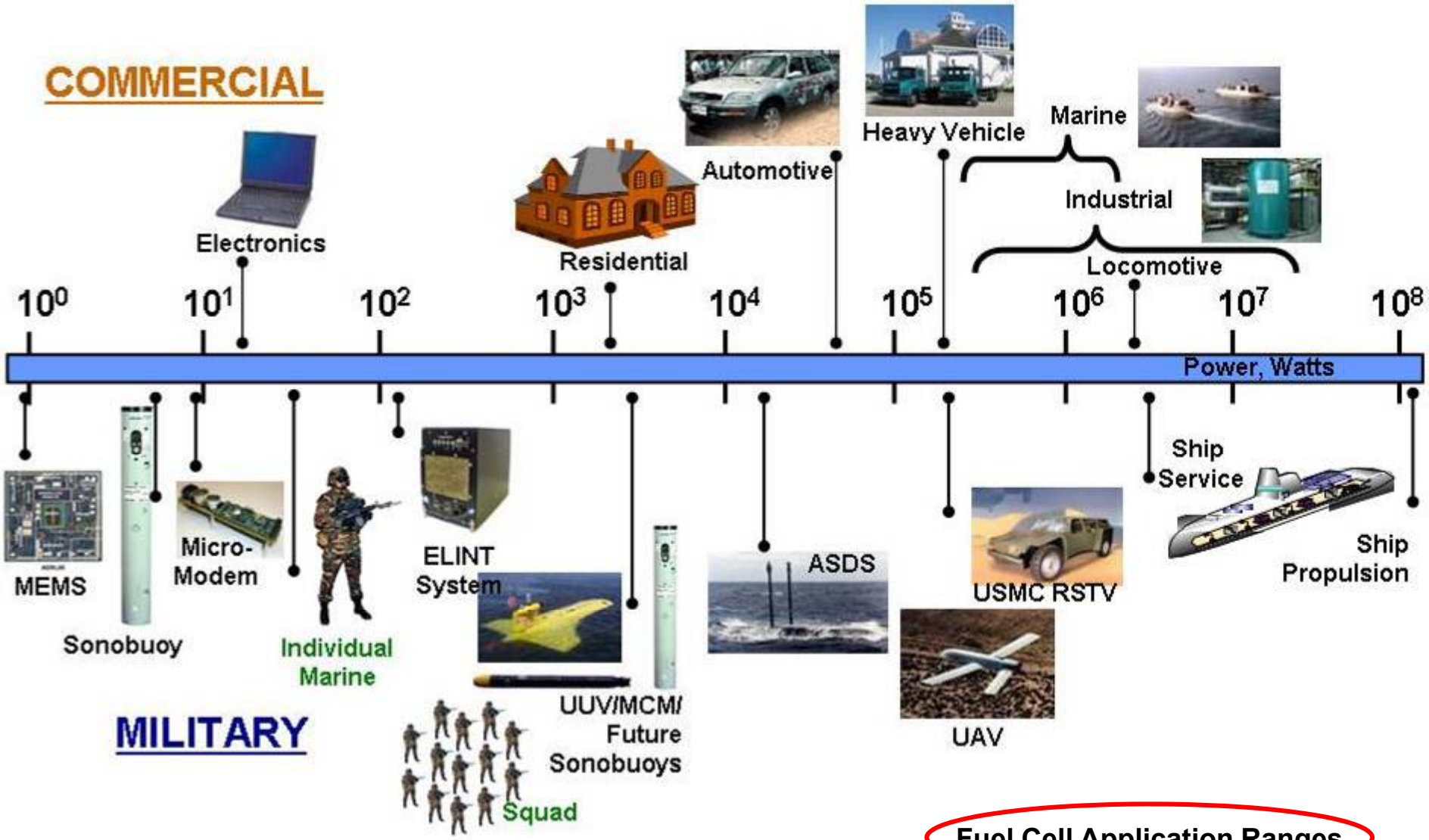
Climate Change????

DoN Energy Targets*

- Lifecycle energy costs of platforms, weapons systems, and buildings, the fully-burdened cost of fuel in powering these, and contractor energy footprint will be mandatory evaluation factors used when awarding contracts.
- Navy will demonstrate a Green strike group of nuclear vessels and ships using biofuel in local operations by 2012. By 2016, Navy will sail a "Great Green Fleet" composed of nuclear ships, surface combatants with hybrid electric power systems using biofuel, and aircraft flying only on biofuels.
- By 2015, DoN will reduce petroleum use in the commercial fleet of 50,000 vehicles by 50% by phasing in a composite fleet of flex fuel, hybrid electric, and neighborhood electric vehicles
- By 2020, at least half of the DoN's shore-based energy requirements will come from alternative sources.
- By 2020, half of total DoN energy consumption will come from alternative sources.

*** From 26 Oct 2009 *Rhumb Lines***

Application Power Requirements

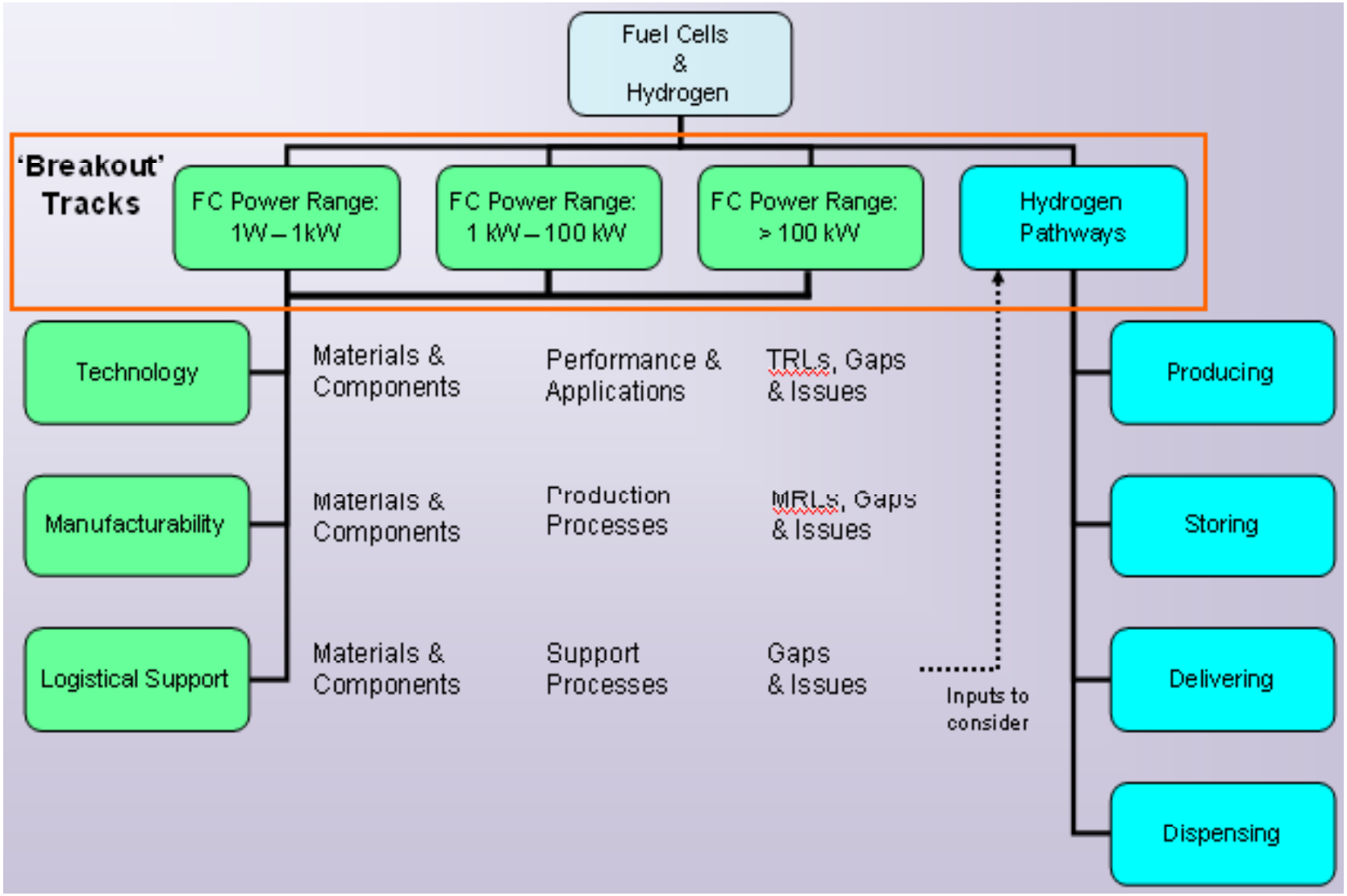


Fuel Cell Application Ranges

DoD Hydrogen and Fuel Cell R&D

- **Hydrogen Research**
  - **$18M in FY10 (primarily congressionally funded efforts)**
    - **Biocatalysts for H2 production**
    - **Reformation of logistics fuels**
- **Fuel Cell Research & Demonstration**
  - **~$35M in FY10**
    - **Basic and applied research in catalysts and materials (~1/3 congressionally funded)**
    - **Unmanned systems, deployable field units and man portable applications**
- **Fuel cell powered vehicles**
  - **Fork lifts**
  - **Flight line support vehicles**
  - **Base / local transportation vehicles**
  - **Tactical combat vehicles**
  - **Unmanned vehicle power**
- **Fuel cell stationary power**
  - **Grid stabilization**
  - **Back-up power**
  - **Off-grid stand alone**

DOD/DLA Fuel Cell Hydrogen Roadmap



Fuel Cell Application Ranges

Table 1. Fuel Cell Type versus Fuel Used and Power Range Supported

Fuel Cell Type	Fuel Used	Power Range	1W - 1kW	1kW-100kW	> 100kW
Direct Methanol Fuel Cell (DMFC)	Methanol	1W-500W	■		
Reformed Methanol Fuel Cell (RMFC)	Methanol and Water	1W-500W	■		
Small Solid Oxide Fuel Cell (SOFC)	Propane, Butane, Methane	1W-500W	■		
Chemical Hydride Fuel Cell	Sodium Borahydride, Ammonia Borane	1W-1kW	■		
Proton Exchange Membrane (PEM)	Hydrogen	1W-100kW	■	■	
Solid Oxide Fuel Cell (SOFC)	Propane, Butane, Methane	1W - 500kW	■	■	■
Reformed PEM	JP-8, JP-5, Diesel	250W-500kW	■	■	■
Reformed SOFC	JP-8, JP-5, Diesel	250W-500kW	■	■	■
Molten Carbonate Fuel Cell (MCFC)	Natural Gas, Coal	>40kW		■	■
Phosphoric Acid Fuel Cell (PAFC)	Hydrogen, Natural Gas	>100kW			■
Direct Carbon Fuel Cell (DCFC)	Carbon, graphite, coal, coke, tar, biomass, organic waste	>100kW			■

Table 2. Applications versus Power Ranges

Application	Power Range	1W - 1kW	1kW-100kW	> 100kW
Soldier-carried Power	1W-100W	■		
Man-portable power	100W -500W	■		
Auxiliary Power Unit	500W-10kW	■	■	
Mobile Electric Power	1kW - 100kW		■	
Large Stationary Power & Shipboard Power	>100kW			■

DoE / DoD / DLA Coordinated Deployments

FY2008 – 4 interagency agreements to deploy 43 backup power fuel cells

- Fort Jackson, South Carolina – 10 fuel cells (Telecommunications Center, Energy Monitoring and Control Facility, Emergency Services Center)
- Los Alamitos Joint Forces Training Base, CA – 4 fuel cells (Fire Station)
- Marine Corps Logistics Base Barstow, CA – 4 fuel cells (Fire Station)

FY2009 – Army-CERL Broad Agency Announcement to deploy up to 87 fuel cells for backup power at 13 locations across the country

- Argonne National Laboratory, IL
- Cheyenne Mountain Air Force Station, CO
- Aberdeen Proving Ground, MD
- Fort Bragg, NC
- Fort Hood, TX
- Fort Irwin, CA
- Ohio National Guard
- Picatinny Arsenal, NJ
- NASA Ames Research Center, CA
- Marine Corps Air Ground Combat Center 29 Palms, CA
- U.S. Military Academy at West Point, NY
- Fort Richardson, AK
- National Park Service Fort Sumter, SC

FY2010 –

- APTO: ground support equipment and H2ICE shuttle buses
- DLA: material handling equipment and H2ICE shuttle buses
- Army incl. CERL/TARDEC: backup power, waste to energy, and H2ICE shuttle buses
- NPS: renewably generated backup power and H2ICE shuttle buses
- ONR/USMC: utility scale renewable hydrogen generation and H2ICE shuttle buses

Fort Jackson Project

DOE and Army-CERL teamed in a project to deploy 10 fuel cell backup power units at Fort Jackson

Backup Power Solution

- Telecommunications Center (30 kW): six 5 kW fuel cells
- Energy Monitoring and Control Facility (5 kW): one fuel cell
- Emergency Services Center (15 kW): three fuel cells
- Plug Power is the manufacturer of the fuel cells

Partners

- DOE
- South Carolina
- U.S. Army Corps of Engineers (ERDC-CERL)
- Fort Jackson

This is a purchase of commercial products

Project to include eighteen month data collection period, providing important third-party test data to validate performance characteristics and help increase consumer acceptance of fuel cell technologies. Fort Jackson to operate and maintain fuel cells for remaining lives of the products.

Los Alamitos JFTB Project

Potential "Model" for DOD-Led Cross-Cutting Renewable Energy Generation: The Los Alamitos JFTB

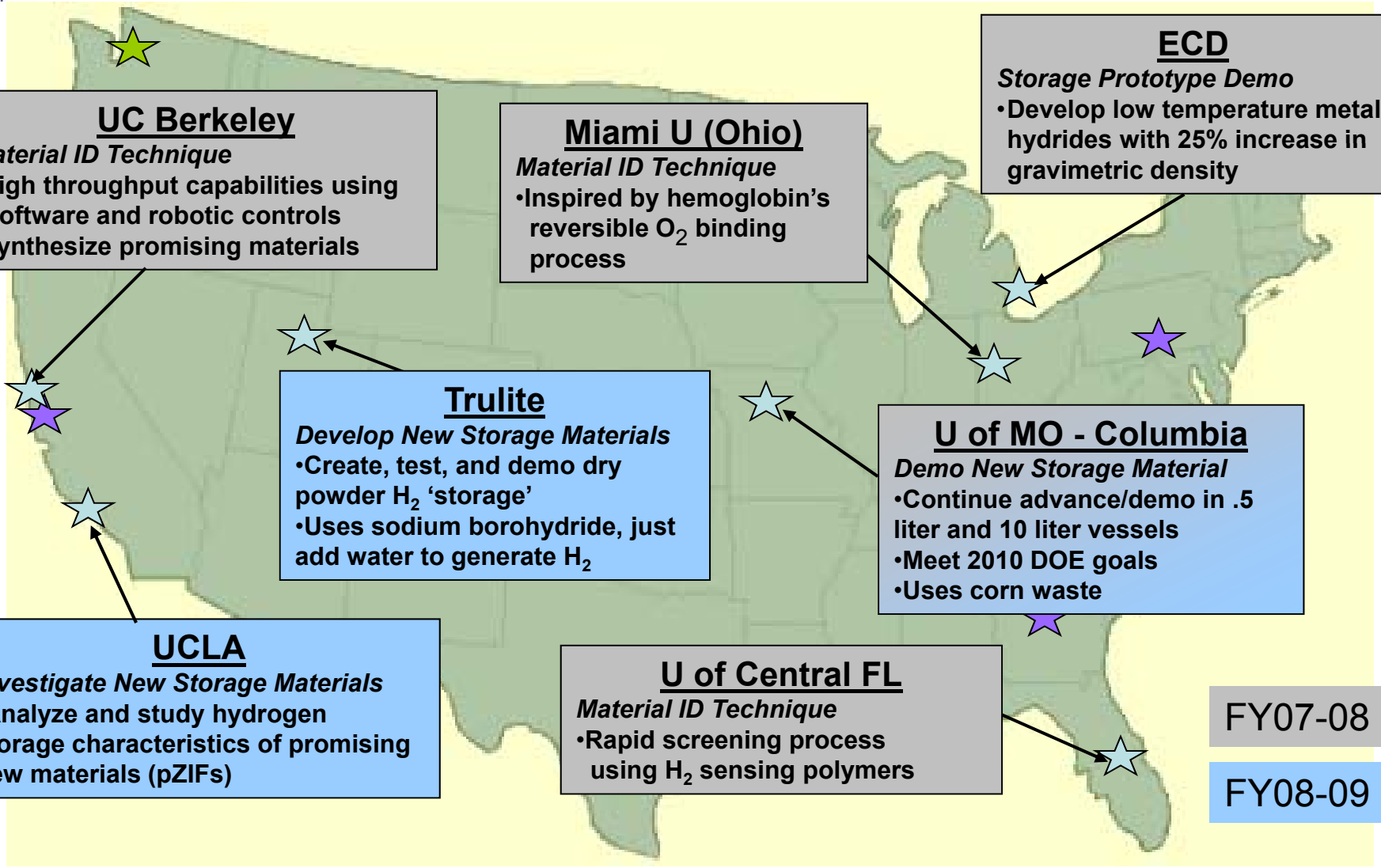
Phase One: Photovoltaic/Hydrogen Generation/Backup Power Demonstration and Feasibility Study

- 10 kW solar PV array, Electrolyzer, and four 5 kW fuel cells (20 kW)
- Feasibility Study: Evaluate Technical and Economic Merits of Integrated Renewable Energy to Achieve Long-Term Net Zero Energy and Carbon Footprint Goals

Recommended Renewable Energy Solutions (Based on Feasibility Study)

- Potential for Substantial Increase of Solar Capacity
  - JFTB monthly demand (about 500,000 kWh) could be supplied on-site by PV using only about 1/33rd of total available space
- Potential for On-Site Green-Waste to Energy – potential to reform up to 1,000 tons/day of biomass
  - Potential to produce enough electricity to power 125,000+ homes
  - Potential to produce enough hydrogen to fuel 18,000+ vehicles
- Consider 'Smart-Grid' use of on-site resources, including potential for hydrogen fueling station – electric utility interconnect agreements and gas utility tariffs need to be addressed
- Consider additional electrolyzer and backup power capabilities

Other DLA Initiatives: Solid H_2 Storage R&D



UC Berkeley
Material ID Technique
- High throughput capabilities using software and robotic controls
- Synthesize promising materials

Miami U (Ohio)
Material ID Technique
- Inspired by hemoglobin's reversible O_2 binding process

ECD
Storage Prototype Demo
- Develop low temperature metal hydrides with 25% increase in gravimetric density

Trulite
Develop New Storage Materials
- Create, test, and demo dry powder H_2 'storage'
- Uses sodium borohydride, just add water to generate H_2

U of MO - Columbia
Demo New Storage Material
- Continue advance/demo in .5 liter and 10 liter vessels
- Meet 2010 DOE goals
- Uses corn waste

UCLA
Investigate New Storage Materials
- Analyze and study hydrogen storage characteristics of promising new materials (pZIFs)

U of Central FL
Material ID Technique
- Rapid screening process using H_2 sensing polymers

FY07-08

FY08-09

DLA's Hydrogen and Fuel Cell Program

4 Fuel cell forklift demonstration projects

Approach:

- Pilot multiple H_2 generation, dispensing and fuel cell technologies to power Material Handling Equipment (MHE) in warehouse operations
- Analyze operational data to establish an operational business case

Collaborators:

3 Leading Fuel Cell Mfg, 2 Leading Hydrogen Mfg, DLA/DOE/NSWC Crane/NREL with multiple Prime Contractors

Funding (Congressional):

Locations:

DDSP: 40 forklifts, delivered (cryogenic) H_2, indoor dispensing

DDWG: 20 forklifts, onsite natural gas reformation for H_2, mobile refueling

DDJC: 20 forklifts, electrolysis for H_2, Power Purchase Agreement (Solar)

Ft. Lewis: 19 forklifts, 1 bus, wastewater digester gas H_2, mobile refueling

Duration: 2 years each

Business case analysis: Performance/cost data collected by NREL & LMI

DLA Fuel Cell Forklift Demonstration Projects

Defense Depot Susquehanna, PA

Approach:
- First in series of 2-year demo projects
- Compare two fuel cell producers
- National Renewable Energy Lab (NREL) to collect and analyze operational data
- Business case analysis

Performers:
- **Air Products** - infrastructure and integration
  - Plug Power (20 new units)
  - East Penn/Nuvera (20 retrofit units)

Funding: ~$5.3M

Accomplishments/Milestones:
- Contract awarded/Kick-off – August 2007
- Planning/design/permitting – September 2008
- Construction start – October 2008
- ***Ribbon Cutting – February 10, 2009***

Features:
- Add 20 new fuel cell forklifts
- Retrofit 20 forklifts with fuel cells
- Indoor dispensing system for delivered liquid H_2

DLA Fuel Cell Forklift Demonstration Projects

Defense Depot Warner Robins, GA

Approach:
- Expand to include on-site H2 reformation and mobile refueling
- Add to NREL data collection/business case
- Teaming: Robins AFB/ USAF Advanced Power Technology Office (APTO)

Performers:
- **Concurrent Technologies (CTC)** - Integrator
  - Air Products – Infrastructure/mobile unit
  - Hydrogenics – Fuel cells (20 new units)

Funding: ~$4.8M

Accomplishments/Milestones:
- Contract award – June 2008
- Planning/Design/permitting – January 2009
- Construction start – January 2009
- Initial ops/Ribbon Cutting – January 2010

Features:
- 20 forklifts with fuel cells
- H_2 reformed on site from natural gas
- Test mobile refueling
- Looking for additional hydrogen demand (extended range vehicles)

Hickam AFB Technology Program

Goal: Facilitate demonstration/validation of the latest fuel efficient and environmentally compliant technologies for use in Air Force support equipment, Basic Expeditionary Airfield Resources (BEAR), base infrastructure, and ground vehicle fleets; establish a National Demonstration Center at Hickam AFB.

Deployable H_2 Refueling Station

Milestones

- Introduce fuel cell technology at Hickam AFB
- Develop and evaluate fuel cell powered vehicles
- Determine hydrogen infrastructure requirements
- Develop deployable hydrogen refueling station
- Introduce renewable energy to produce hydrogen
- Establish model for future Air Force procurement

Hickam AFB Renewable H_2 Production and Fueling Station

Deployable Modules

- **Hydrogen Fuel Processor (H_2FP) uses two electrolyzers; produces up to 50kg/day.**
- **Hydrogen Pressure Management (H_2PM) pressurizes H_2 up to 5000psi.**
- **Hydrogen Pressure Storage (H_2PS) stores H_2 at 5000psi.**
- **Water filtration**
- **Power Control**
- **MEP 9 Generator for deployment**
- **Operating since Nov 2006**

146 kW Photovoltaic Array

- **Provides power to base grid when station is not operating.**
- **Operating since May 2009**

Five 10 kW Vertical Axis Wind Turbines

- **Additional renewable energy for hydrogen station; power to base grid when station is not operating.**
- **Scheduled completion by Feb 2010.**

Transportation Applications

Non-tactical hydrogen-powered
General Motors Fuel Cell Vehicles

Marine Corps Base Camp Pendleton

Expeditionary Power

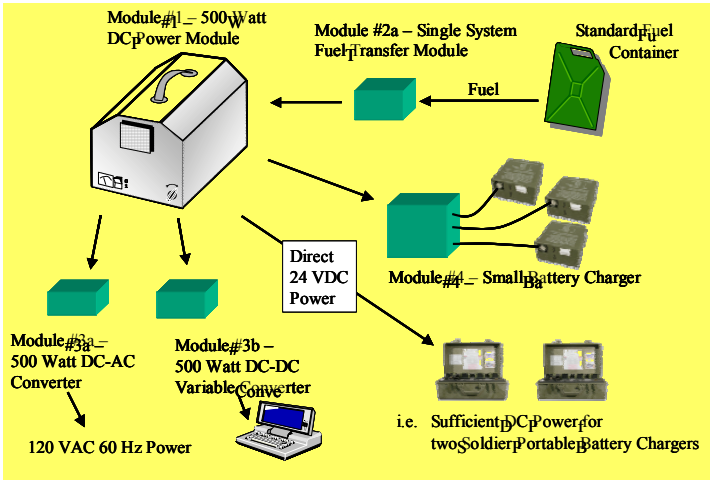
Solid Oxide Fuel Cell for Tactical Vehicle APU and Towable Generator

Solid Oxide Fuel Cell

Efficient, low emission, and low signature

Vehicle Based

Towable Power



Single Person Portable Power Generator

Autonomous Vehicles – High Power Fuel Cell Propulsion
The "Ion Tiger"

S&T OBJECTIVES

Fuel cell system integration program to develop fuel cell propulsion systems for the *"Ion Tiger" specifications:*

- 24-hours flight endurance
- 5-pound payload
- 35-pound gross take off weight
- low heat and noise signature

APPROACH

- Polymer fuel cell with high specific power ~1000 W/kg stack; 500 W/kg system
- High pressure, lightweight hydrogen storage tanks
- Systems engineering to optimize flight endurance
- Protocols to improve fuel cell durability in naval environments
- *Collaborators: P0rotonex Technology*

Results / Impact / Readiness

- Increased operational temperature of polymer fuel cell to make it more viable in military environments (improved heat rejection in hot weather)
- Designed tanks with >10 weight percent hydrogen storage
- Developed electrochemical protocols to remove air-borne poisons from fuel cell catalysts
- 23 hour 17 minute fuel cell powered flight in October 2009
- **26 hour fuel cell powered flight in November 2009**

50 & 300 Watt Fuel Cells

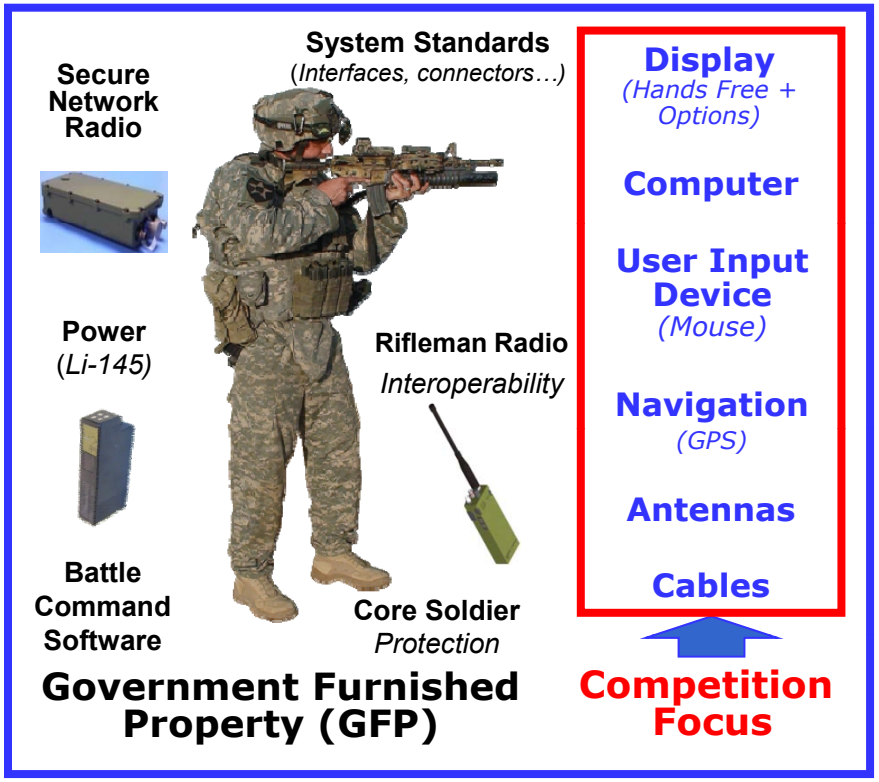
(ARRA Funding)

Technical Objectives

- Scale up existing fuel cell designs
  - 25 watt to 50 watt
  - 250 watt to 300 watt
- Improve MTBF & ruggedization of current designs
- Design to:
  - Charge BB-2590, LI-145 & BB-521 batteries
  - Provide power to standard Army charger
- Leverage commercial efforts to provide common technical baseline that will benefit all (i.e., the "tipping point")
- Develop & implement a manufacturing maturity plan to increase quality & decrease unit cost

Impact

- Decreased dependence on fossil fuel generators
- Increased ability for use of rechargeable batteries in remote locations
- Manportable, silent energy source
- Increased user acceptance
- First Fieldings
  - USAF Battlefield Airman Operator Kit Increment II
  - Ground Soldier System (2012)
  - Other uses are as power source for standard Army chargers, remote sensor locations and portable APU applications
- Usage expected to increase as unit cost decreases and reliability increases



Team Members

- Government
  - 50 Watt – USAF Wright Lab
  - 300 Watt –Army Power Div.
- Contractors
  - Adaptive Materials
  - Bren-Tronics
  - Protonex

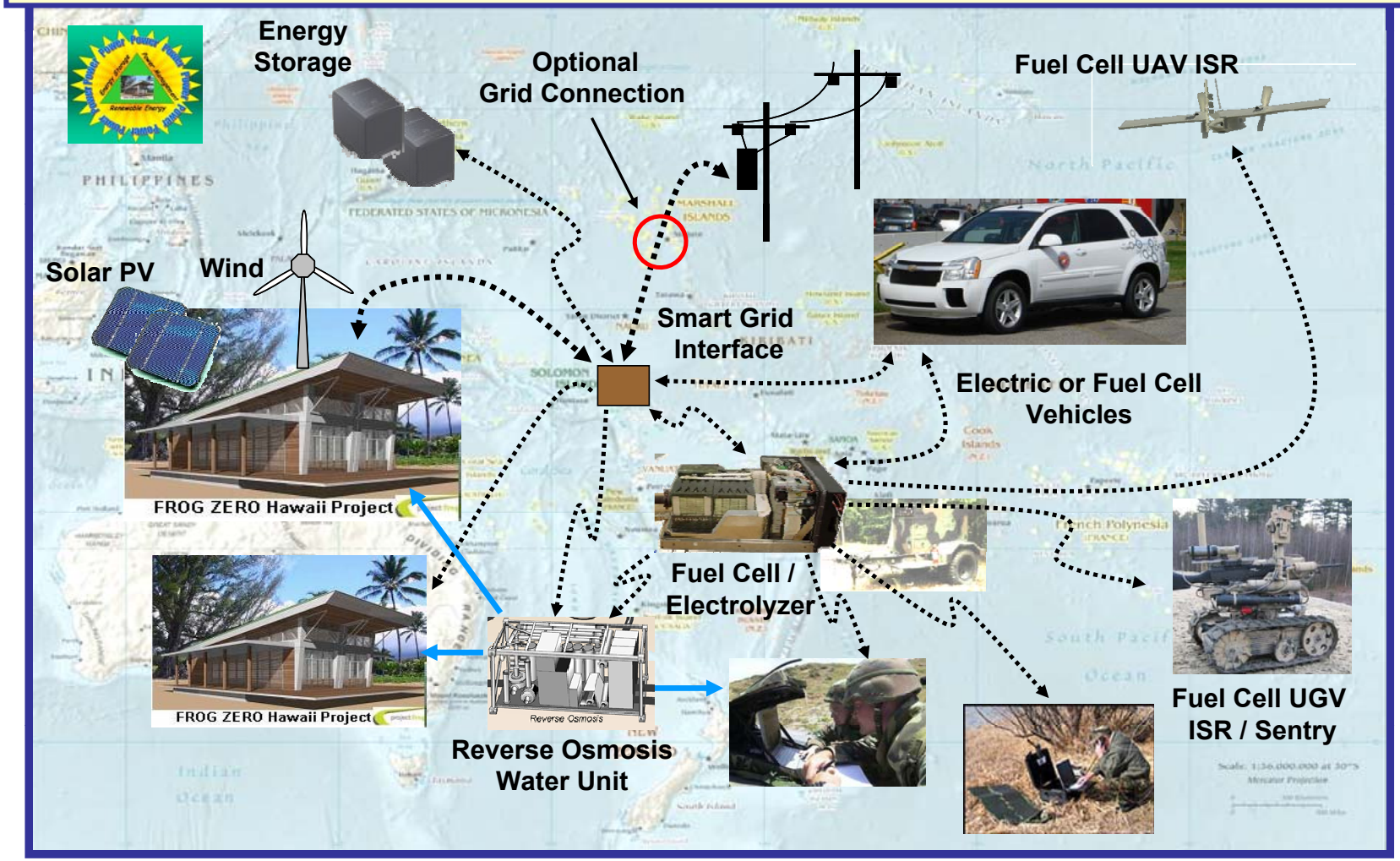
Funding

- Total $18,5M [$6.3M - 50 watt: $12.2 – 300 watt]

Alternative Energy Research for the Pacific Environment

Hawaii as the Defense Energy Model for the Pacific Island Region

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



Hawaii Energy & Environmental Technologies (HEET) Initiative

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

S&T OBJECTIVES

- Conduct research to understand performance and durability limitations of PEM fuel cells
- Evaluate suitability of PEM and SOFC power systems for applications-specific conditions
- Develop critical technologies supporting reforming of logistic fuels
- Explore potential of utilizing seabed methane hydrates for seafloor power generation

APPROACH

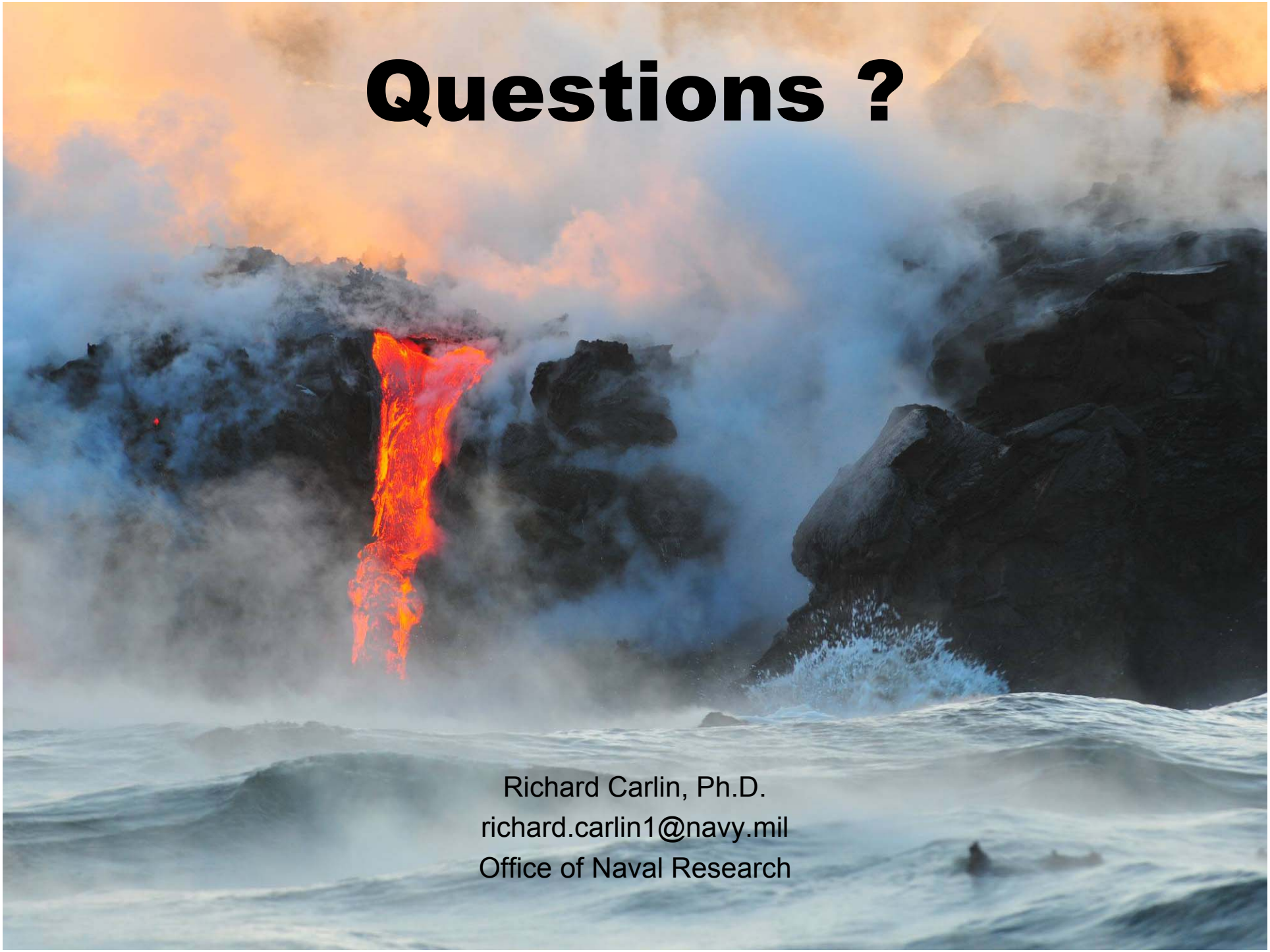
- Experimental studies of fuel cell performance response to stresses including trace impurities, and drive and temperature cycling.
- Experimental studies using Hardware-in-Loop (HiL) for dynamic applications
- Bench-scale testing of advanced reforming technologies including plasma diesel arc
- Integrated Raman probe and high pressure calorimetry for hydrates characterization

Hawaii Fuel Cell Test Facility

Results/ Impact/Readiness

- Fully equipped fuel cell test facility for performance, durability, and HiL testing
- Validated test protocols for SS, cyclic and dynamic testing
- Preliminary experiments demonstrating reforming of logistic fuel at reduced temperature
- Characterization of methane hydrates via simultaneous spectroscopy and high pressure calorimetry underway

Questions ?



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