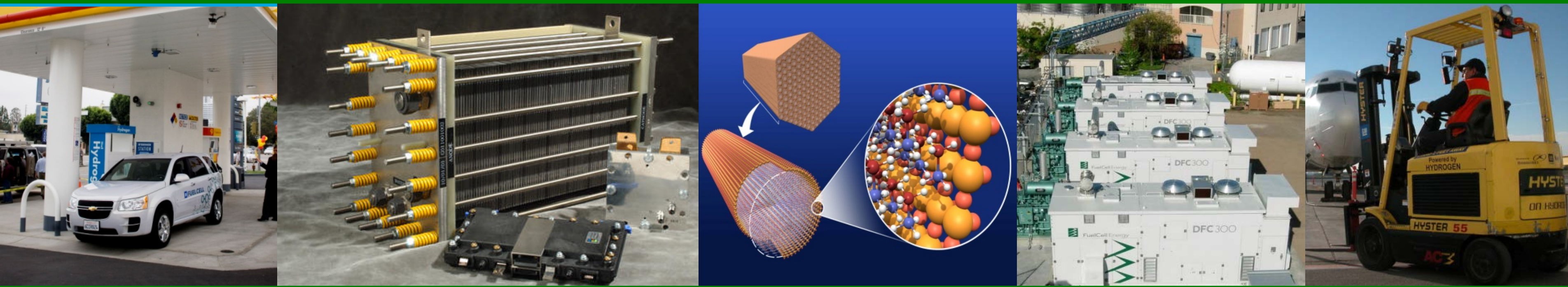
U.S. DEPARTMENT OF
ENERGY



Crosscutting and Validation

(Manufacturing R&D; Technology Validation; Safety, Codes & Standards; Education & Outreach)

Rick Farmer

2013 Annual Merit Review and Peer Evaluation Meeting

May 13, 2013

Goal and Examples of Key Objectives

U.S. DEPARTMENT OF ENERGY

Enable widespread commercialization of hydrogen and fuel cell technologies through manufacturing cost reductions, technology validation, codes and standards development, and education of key stakeholders

Manufacturing

- 2017 - Develop processes to produce compressed hydrogen storage systems to help meet the cost target of \$12/kWh (2010 status - \$19/kWh)
- 2017 - Develop manufacturing techniques to reduce the cost of automotive fuel cell stacks from \$38/kW (2008) to \$21/kW

Technology Validation

- 2017 - Validate commercial stationary fuel cells (100 kW to 3 MW) against 2015 system targets (50,000 hours, 45% electrical efficiency).
- 2019 - Validate fuel cell vehicles achieving 5,000 hour durability and 300 mile driving range

Safety, Codes and Standards

- 2015 – Conduct a quantitative risk assessment to address indoor refueling requirements to be adopted by code development organizations
- 2017 - Complete material testing to develop ASME/ASTM hydrogen materials qualification guidelines, including composites

Communication & Outreach

- Utilize webinars to communicate key accomplishments and activities
- Expand case studies of near-term market applications

Examples of Key Challenges

Manufacturing

- Manufacturing processes to produce high volume MEAs, bipolar plates, and balance of plant fuel cell components
- Fabrication processes to attach carbon fiber to conformable tanks

Technology Validation

- Insufficient data on fuel cell electric vehicle performance and durability
- Insufficient data on refueling infrastructure performance

Safety, Codes and Standards

- Insufficient data to provide the scientific basis for technically sound codes and standards
- Harmonizing domestic and international regulations, codes and standards

Communication & Outreach

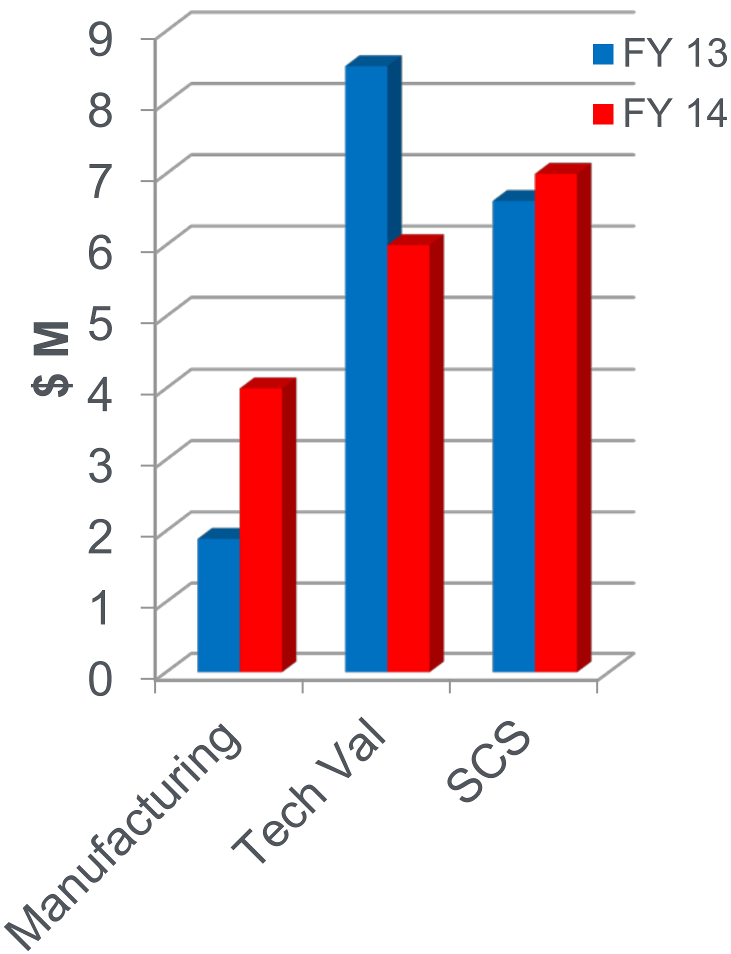
- Resistance to change
- Lack of educated trainers and training opportunities

Crosscutting and Validation Budgets

U.S. DEPARTMENT OF ENERGY

FY 2014 Request - $17.0 M

FY 2013 Actual - $17.0 M



Outreach is planned under all key activities
Educaton for teachers and curricula development is deferred to outyears

EMPHASIS

Manufacturing

- Continue core efforts on PEM fuel cells
  - Develop real-time, online measurement tools
  - Simplify roll-to-roll processing of MEAs
- Collaborate with Advanced Manufacturing Office and Clean Energy Manufacturing Initiative

Technology Validation

- Data collection and analysis of fuel cells used in vehicles, fork lifts, backup power, buses, and trigeneration systems
- Demonstration and evaluation of advanced fueling components

Safety Codes and Standards

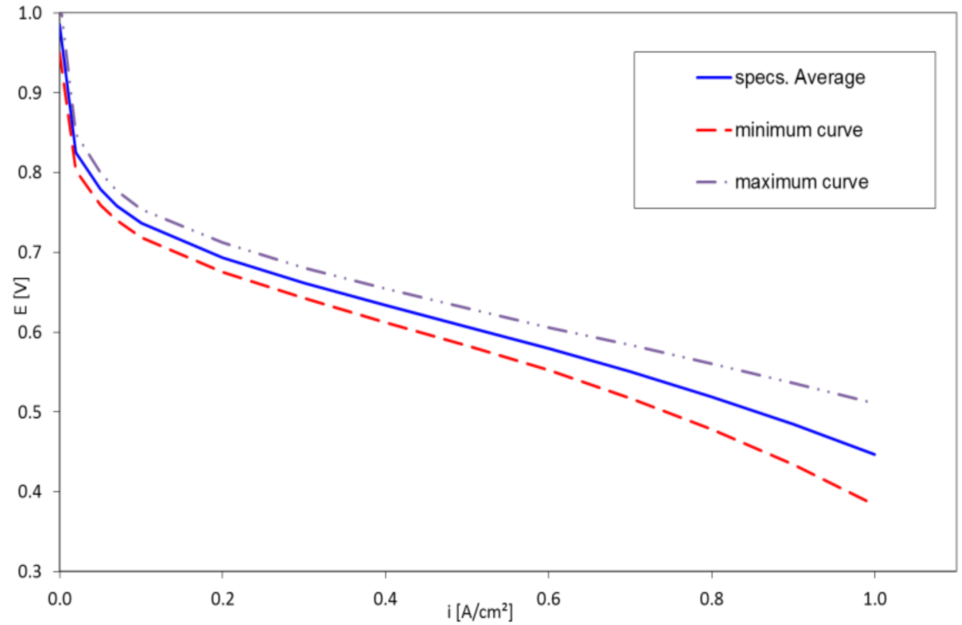
- Develop technical information and performance data to enhance codes and standards
- Facilitate the permitting of hydrogen fueling stations and early market applications

Manufacturing Progress

U.S. DEPARTMENT OF ENERGY

BASF's new Celtec® P1100W product based on DOE project

- **Status:** 2012 AMR demonstrated production scale multi-step microporous layer (MPL) fabrication. 2012/13 focus was on single application steps for MPL and catalyst layer
- **Approach**: Increase solids content (and thus viscosity) of ink without loss of stability. Investigate alternative application process to handle higher viscosity inks
- **Results**: Scaled single-pass MPL to production coating machine. Pilot scale single-pass with catalyst. All at ½ width.



Improvement vs. best cloth

Cost (hrs. or material)	% reduction
Coating Time (1/2 width)	28
Coating Time (full width)	64
Base Material Cost*	44
Ink Time	pilot scale

* 3,000 5-kW systems

Project Accomplishments

- Achieved 4X throughput increase exceeding 3X project goal
- Reduced total gas diffusion electrode labor costs ~75%
- Launched new product based on this work

Manufacturing Progress

U.S. DEPARTMENT OF ENERGY

Ion Power to demonstrate NREL's (in-plane) IR/DC technique on their own coating line (transfer from lab to industry)

Approach

Understand quality control needs from industry partners and forums

Develop diagnostics

- Use modeling to guide development
- Use in-situ testing to understand the effects of defects

Validate diagnostics in-line

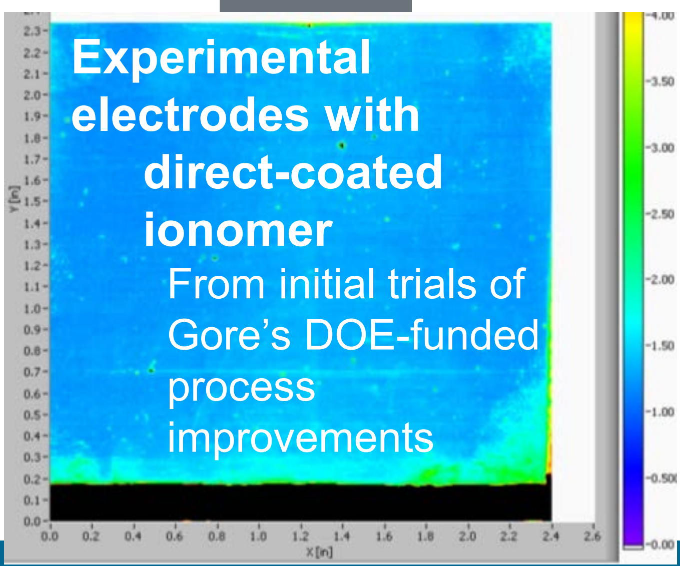
Transfer technology

NREL NATIONAL RENEWABLE ENERGY LABORATORY

BERKELEY LAB

Optical diagnostics

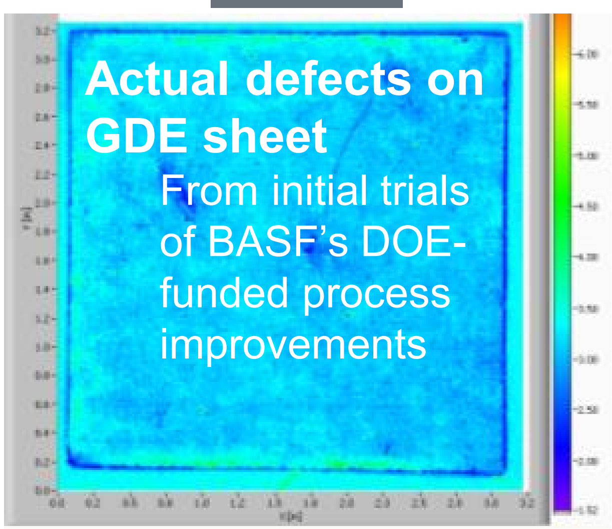
CCMs



Experimental electrodes with direct-coated ionomer

From initial trials of Gore's DOE-funded process improvements

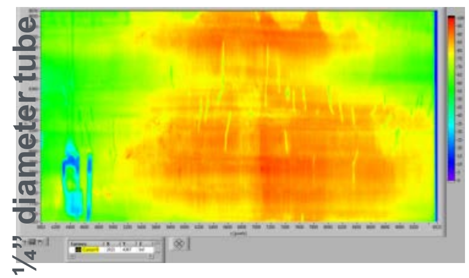
GDEs



Actual defects on GDE sheet

From initial trials of BASF's DOE-funded process improvements

SOFC Tubes



- Fired tubes (anode + electrolyte)
- Detected defects of ~1 mm

PEMFC and SOFC Manufacturing: Status vs. Needs

U.S. DEPARTMENT OF ENERGY

PEM Fuel Cells

Current MEA
- Large batch mixing
- Roll-to-roll processes for membrane, electrode, and GDL fabrication
- Decal transfer of electrode to membrane
- Manual assembly of MEA with seals
- Hot pressing

Advancements
- Continuous mixing
- Robotic or roll-to-roll assembly of MEAs with seals
- Direct coating of electrode on membrane
- Hot-roll lamination or improved pressing

Current Stack
- Manual assembly
- Manual leak/performance test

Advancements
- Automated assembly
- Automatic leak/performance test

Current BOP
- Lean manufacturing cells and flow
- Unique components

Advancements
- Standardized designs
- Robotic BOP/system assembly line

Solid Oxide Fuel Cells

Current Cell
- Large batch mixing of powders and slurries
- Single layer tape casting with lamination of layers (planar)
- Batch pressing or extrusion of tubes (tubular)
- Semi-automated coating of electrolyte and cathode (tubular)
- Batch heat treatment and sintering
- Manual assembly of cells with seals
- Manual winding of interconnect wire (tubular)

Advancements
- Continuous mixing
- Multi-layer tape casting (planar)
- Continuous pressing or extrusion of tubes (tubular)
- Continuous firing and sintering
- Robotic assembly of cells with seals
- Automated winding of interconnect wire (tubular)

Current Stack
- Manual assembly
- Manual shaping of insulation
- Manual leak/performance test

Advancements
- Automated assembly
- Net-shape or other methods for insulation
- Automatic leak/performance test

Current BOP
- Manual assembly
- Unique components

- Lean manufacturing cells and flow

Advancements
- Standardized designs
- Robotic BOP/system assembly line

Clean Energy Manufacturing Initiative

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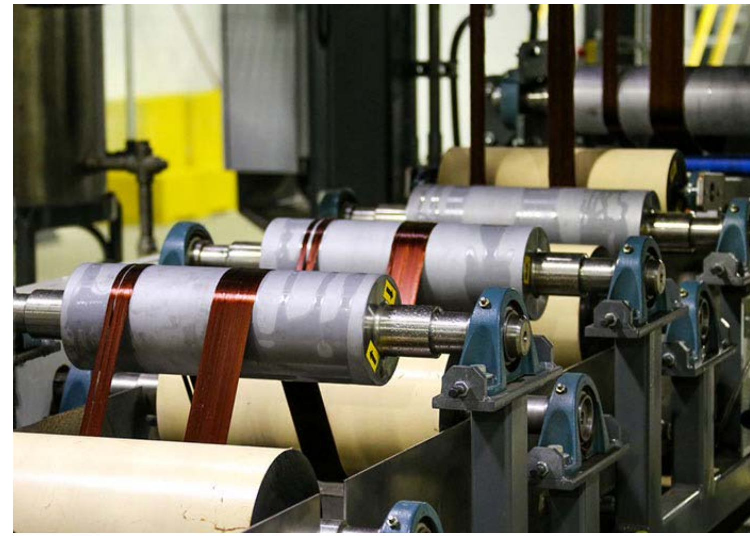
Increase U.S. competitiveness in clean energy products



- **Highlights**:
  - Announced March 26, 2013
  - Increased funding for manufacturing R&D across the board
  - Increased EERE focus on energy productivity resources for manufacturers
  - Development of competitiveness analysis and strategies
  - A clean energy manufacturing portal
  - Regional and national summits
  - New partnerships and engagement opportunities

eere.energy.gov/energymanufacturing

Technology Validation Progress

Published final Learning Demonstration report and awarded new projects.

- 3 awards were made to date:
  - ❑ $5 million DOE funding.
  - ❑ Data to be collected from up to ~70 vehicles.
  - ❑ Planned mileage:
    - ✓ Phase 1 = ~190,000 mi
    - ✓ Phase 2 (anticipated) = ~204,000 mi

	Learning Demo	Current Projects
Range (mi)	196-254*	TBD
Efficiency (%)	53-59	TBD
Durability (hrs)	2,521	TBD

** Separately validated 430 mile range.*

Validation of data via NREL:

- Validate light-duty FCEV performance and durability
- Completed data templates and NREL data security procedures.
- Prioritized key analysis topics.

National Fuel Cell Electric Vehicle Learning Demonstration Final Report (July 2012)

http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/learning_demo_final_report.pdf

Technology Validation Progress

U.S. DEPARTMENT OF ENERGY

DOE Awards $2.4M for Hydrogen Station Evaluations and Advanced Refueling Components

<u>350 bar and 700 bar fill capability at all stations</u>.

California State University—Los Angeles (CSULA)

- **Station Location:** Los Angeles, CA (on CSULA campus).
- **Station Characteristics:** Electrolyzer; 30-60 kg H_2/day.

Proton Energy (Proton OnSite)

- **Station Locations:** Wallingford, CT (SunHydro #1) and Braintree, MA (SunHydro #2).
- **Station Characteristics:** 65 kg H_2/day, advanced 57 bar PEM electrolyzer (at SunHydro #1 station); co-located PV array.

California Air Resources Board (CARB)

- **Station Location:** Newport Beach, CA.
- **Station Characteristics:** 100 kg H_2/day; natural gas reforming.

Gas Technology Institute (GTI)

- **Station Locations:** California (North: San Mateo, Cupertino, Mountainview, West Sacramento) & (South: Laguna Niguel, San Juan Capistrano) **.**
- **Station Characteristics:** new 900 bar ionic compression; gaseous or liquid delivered hydrogen.

KEY METRICS

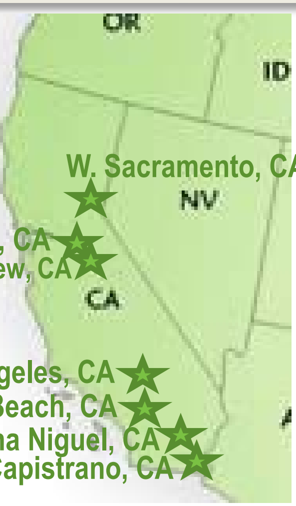
Location/Capacity/Utilization:
Station usage patterns and geographic locations.

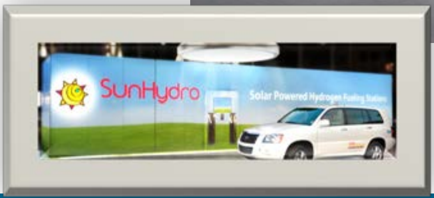
Fueling:
Fueling rates, times, amounts, back-to-back fills, communication.

Maintenance/Availability:
Maintenance patterns, reliability and availability of stations.

Cost:
Energy cost, maintenance cost.

Station Timing:
Permitting time, building time, commissioning time.

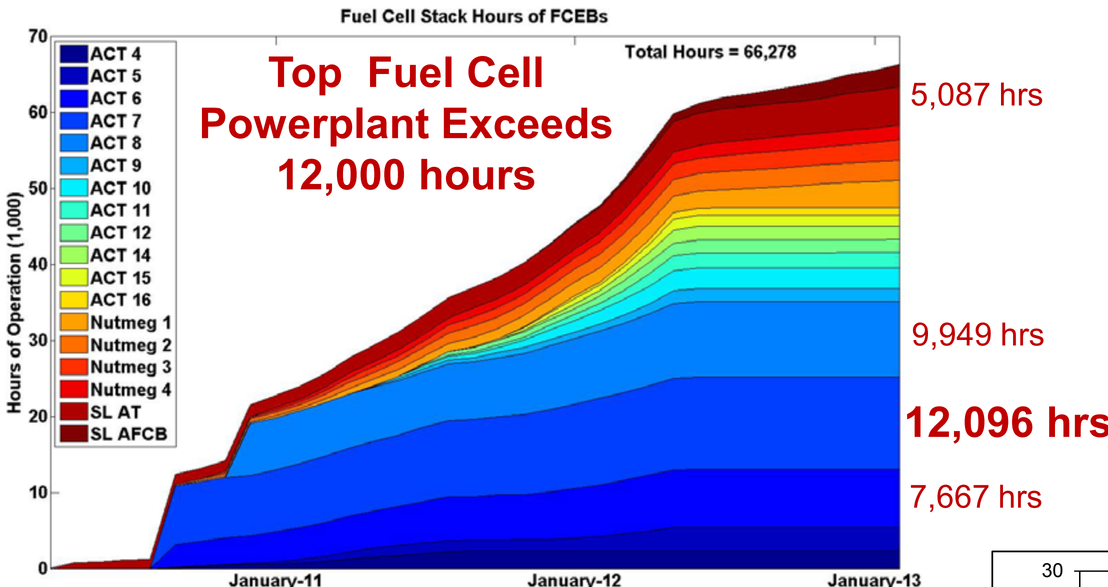




Technology Validation Progress

U.S. DEPARTMENT OF ENERGY

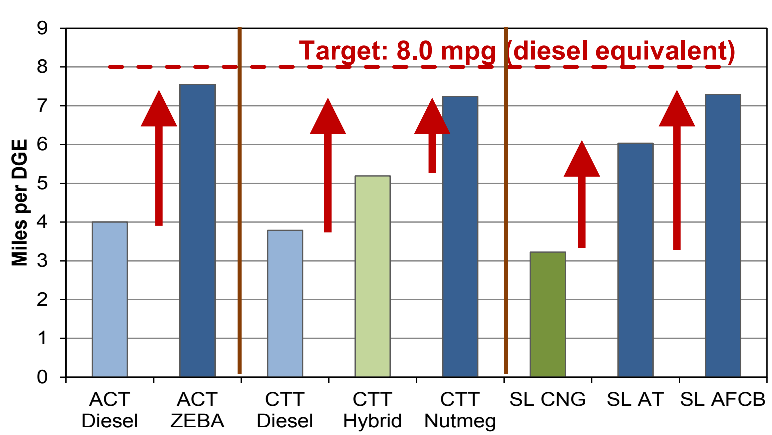
New FC bus designs have twice the fuel economy as diesel buses.

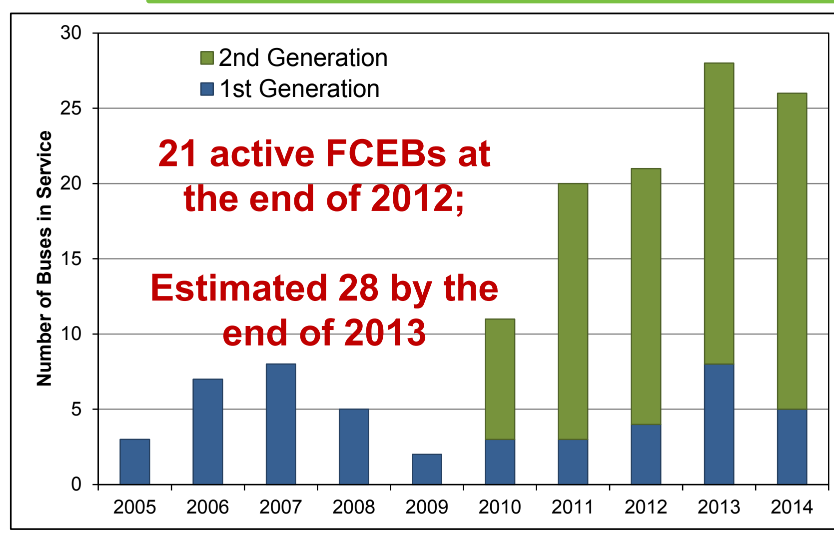


Data Summary for 2012:

- **AC Transit, Oakland, CA**
  - 40-foot Van Hool buses with ClearEdge Power FC (ZEBA)
- **CTTRANSIT, Hartford, CT**
  - 40-foot Van Hool buses with ClearEdge Power FC (Nutmeg)
- **SunLine, Thousand Palms, CA**
  - 40-foot New Flyer bus with Ballard FC and Bluways hybrid system (AT)
  - 40-foot ElDorado bus with Ballard FC and BAE Systems Hybrid drive (AFCB)

13 9:30 AM





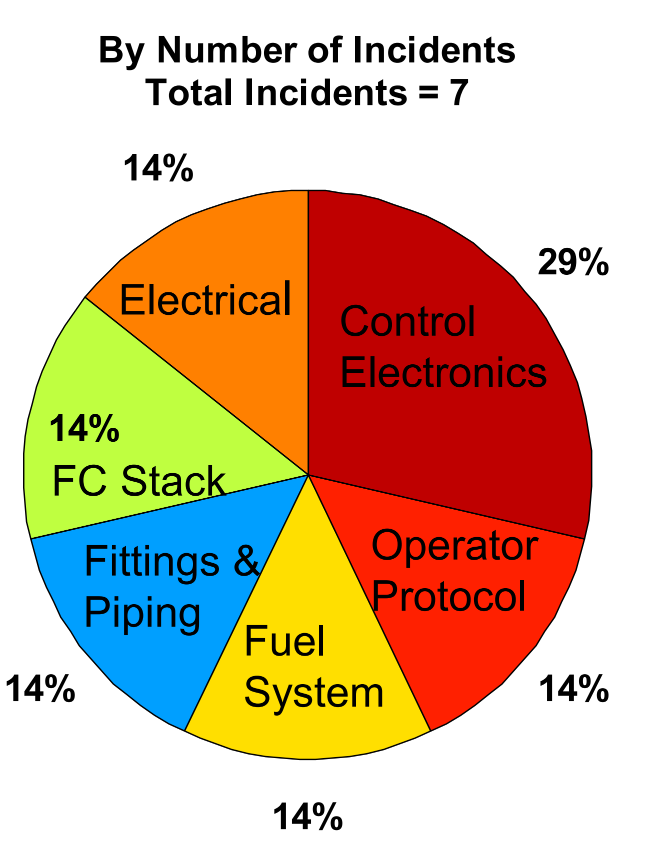
NREL NATIONAL RENEWABLE ENERGY LABORATORY

Safety, Codes and Standards Progress

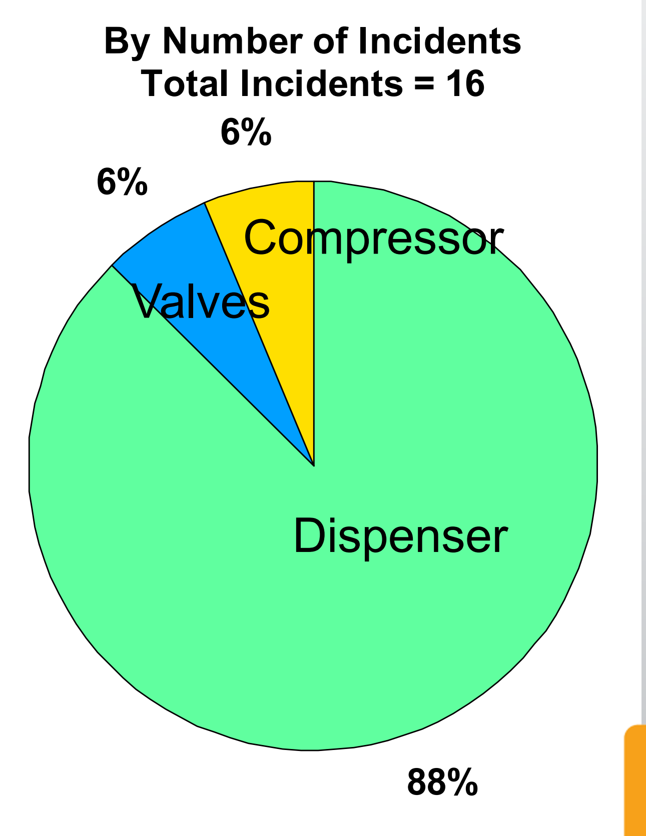
U.S. DEPARTMENT OF ENERGY

Data from material handling equipment help to prioritize R&D and codes and standards activities

Majority of MHE safety reports (217) are minor hydrogen leaks
(4,480 stack hours per report)



Majority of infrastructure safety reports (82) are hydrogen leaks primarily from the hydrogen compressor and plumbing
(3,587 kg dispensed per report)

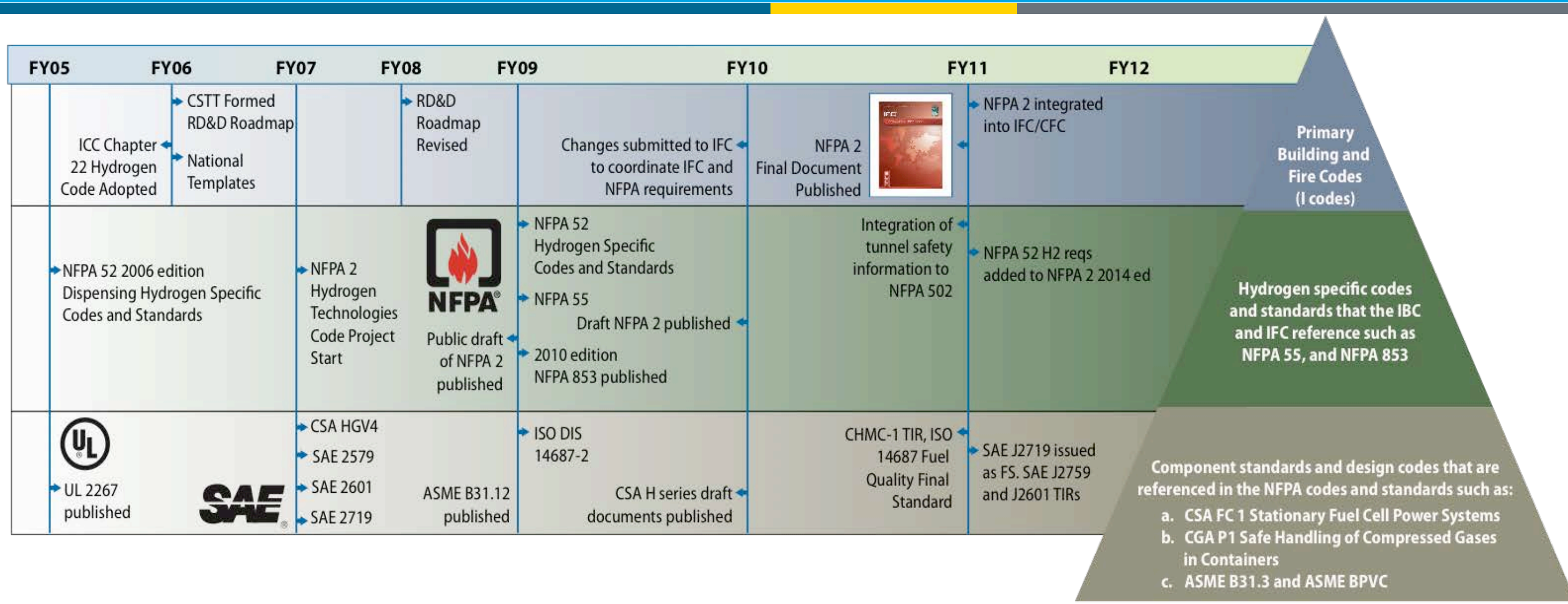


NREL

FORKLIFTS

Safety, Codes and Standards Progress

Timeline of Hydrogen Codes and Standards to enable critical RCS



RCS Accomplishments

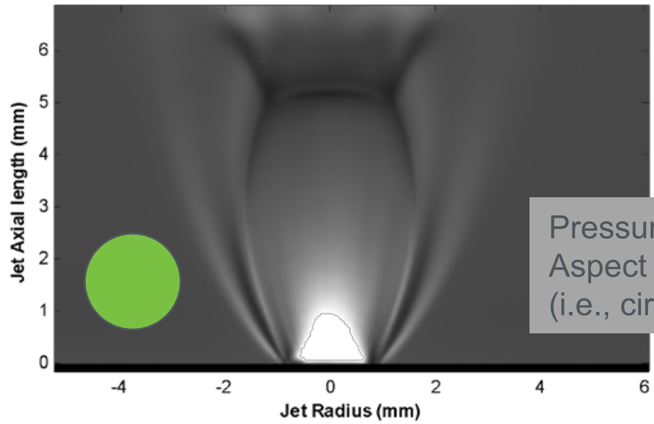
- Initial approval of the **Global Technical Regulation** (GTR) at the the U.N. ECE WP29 in Dec. 2012. Full Acceptance targeted in June 2013. The GTR will become U.S. Federal Motor Vehicle Safety Standard (FMVSS).
- Standard **SAE J2579**, Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles, was published in March 2013
- International Standard on hydrogen fuel quality, **ISO 14687-2**, Hydrogen Fuel–Product Specification– Part 2: Proton Exchange Membrane (PEM) Fuel Cell was approved in Dec 2012

Safety, Codes and Standards Progress

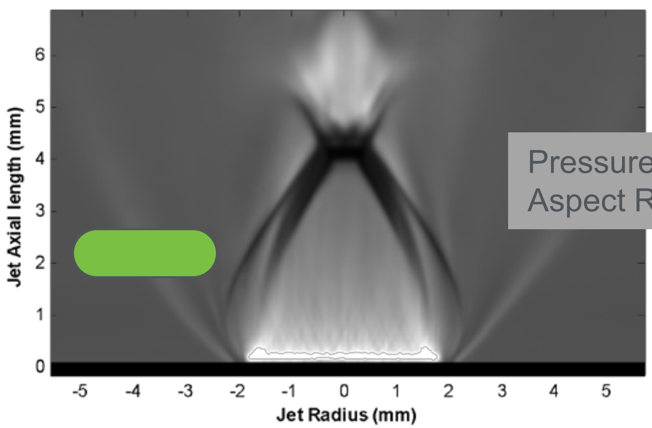
U.S. DEPARTMENT OF ENERGY

Characterization of non-circular releases enables the prediction of release behavior from likely failure mode scenarios such as mechanical damage, leaking fittings, etc.

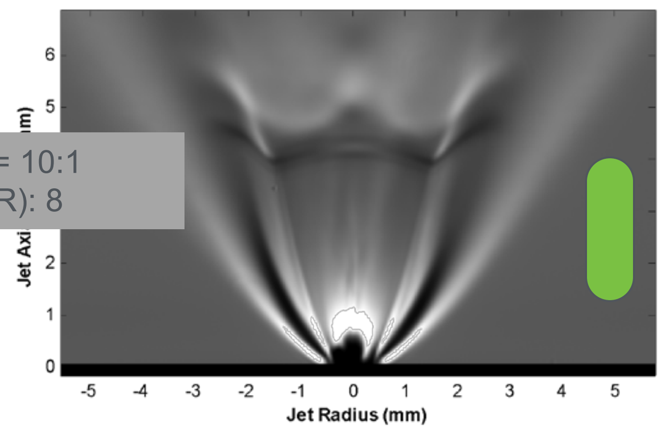
Shown: Schlieren images of jet shock structures at two aspect ratios



Pressure Ratio = 10:1
Aspect Ratio (AR): 1
(i.e., circular)



Pressure Ratio = 10:1
Aspect Ratio (AR): 8



Major Axis

Minor Axis

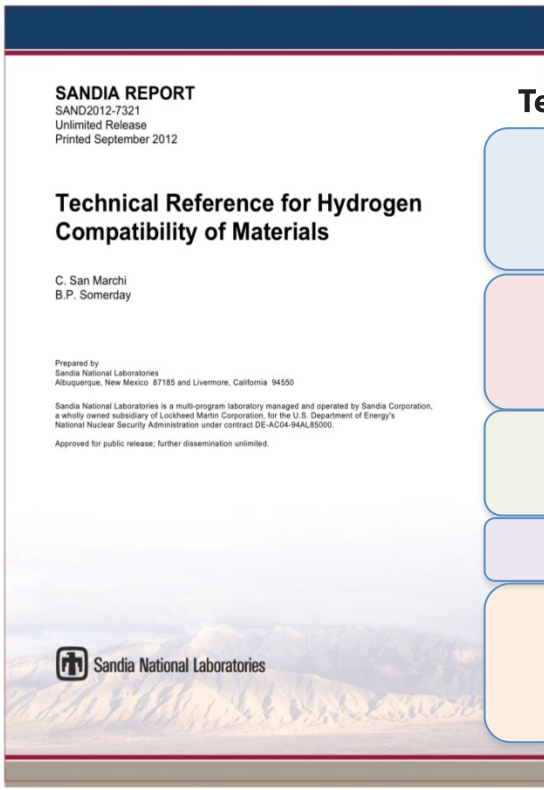
(faster jet spreading rate)

Sandia National Laboratories

Safety, Codes and Standards Progress

U.S. DEPARTMENT OF ENERGY

- Materials compatibility information placed on OpenEI website: http://en.openei.org/wiki/Gateway:Hydrogen
  - Updated full public report on Technical Reference for Hydrogen Compatibility of Materials (SAND2012-7321), 292 pages
  - Datasets for fatigue crack growth of materials in gaseous hydrogen


SANDIA REPORT
SAND2012-7321
Unlimited Release
Printed September 2012

Technical Reference for Hydrogen Compatibility of Materials

C. San Marchi
B.P. Somerday

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Approved for public release; further dissemination unlimited.

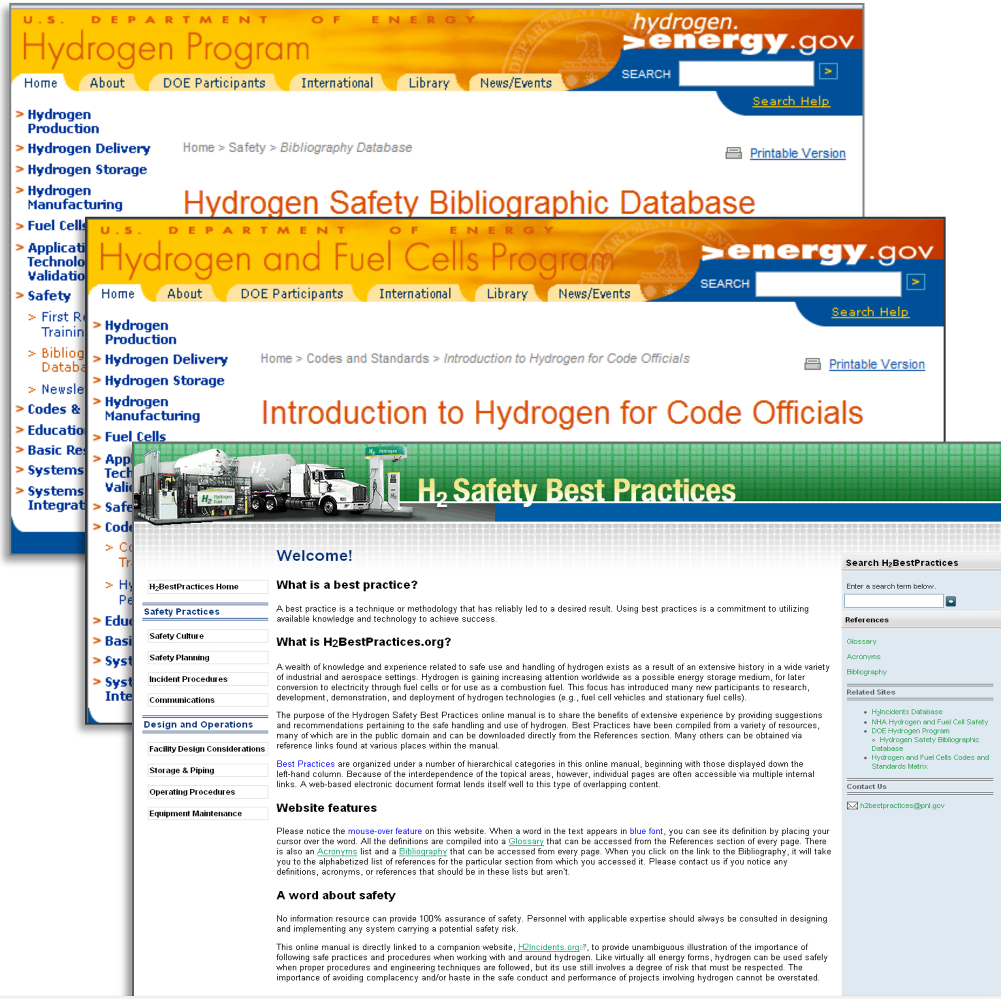
Sandia National Laboratories

Technical Reference	Technical Database
1100 Carbon steels └ 1100: C-Mn alloys	1100 Carbon steels ├ CIA85: tension, fracture, fatigue ├ SAN10: fracture, fatigue └ SAN11: fracture fatigue
1200 Low-alloy steels ├ 1211: Cr-Mo alloys └ 1222: Ni-Cr-Mo alloys	1200 Low-alloy steels └ NIB10: fracture, fatigue
1400-1800 High-alloy steels └ 1401: 9Ni-4Co	1400-1800 High-alloy steels
2000 Austenitic steels	2000 Austenitic steels
3000 Aluminum alloys ├ 3101: Pure aluminum ├ 3210: 2xxx-series alloys └ 3230: 7xxx-series alloys	3000 Aluminum alloys └ SAN11: fracture, fatigue

Sandia National Laboratories

Safety, Codes and Standards Progress:

U.S. DEPARTMENT OF ENERGY



- 208 Lessons Learned events in "H2Incidents.org"
- Approximately 750 entries in the Hydrogen Safety Bibliographic Database

Developed training material for first responders, code officials.

Educated > 26,000 to-date (online & in-person)

www.eere.energy.gov/hydrogenandfuelcells/codes/

Safety, Codes and Standards Progress

U.S. DEPARTMENT OF ENERGY

Discovering New Ways to Share Safety Knowledge

- **First mobile app being developed for end users**
  - Integrates H_2incidents.org and H_2bestpractices.org into a single, searchable, iPad and iPhone application
  - Features include safety planning guidance and checklists
  - All tools (except H_2incidents.org) are available without a data connection
- **New safety knowledge content**
  - 7 safety events added to H_2incidents.org (208 total)
  - H_2bestpractices.org updated to include the safety checklist developed by the Hydrogen Safety Panel

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

International RCS and Partnerships

U.S. DEPARTMENT OF ENERGY

International Partnerships Critical to RCS Harmonization

International harmonization of codes and standards helps ensure the safe implementation and commercialization of hydrogen and fuel cell technologies. The US is working with other countries, SDOs and CDOs to develop these critical elements.

Key RCS Supported by DOE

- SAE J2579 (Fuel Systems for Fuel Cell and other Hydrogen Vehicles)
- GTR Phase 1 (Hydrogen Vehicle Systems)
- NFPA 2 (Hydrogen Technologies)
- ISO 14687-2 (H2 Fuel Quality)
- CSA HPIT 1 (Compressed Hydrogen Powered Industrial Truck)

IPHE

International Partnership for Hydrogen and Fuel Cells in the Economy

iea International Energy Agency

International Energy Agency — Implementing Agreements

hySafe INTERNATIONAL ASSOCIATION FOR HYDROGEN SAFETY

International Association for Hydrogen Safety

ICHS International Conference on Hydrogen Safety

International Conference on Hydrogen Safety

Communication & Outreach

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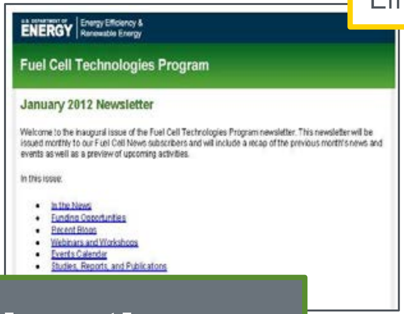
Published more than 70 news articles in FY 2012 (including blogs, progress alerts, DOE news alerts)

- ***Monthly Webinar Series***
  - Hydrogen Refueling Protocols
  - Advanced Electrocatalysts for PEM Fuel Cells
  - Wind-to-Hydrogen Cost Modeling and Project Findings
  - Mobile lighting
  - Register at - http://www1.eere.energy.gov/hydrogenandfuelcells/webinars.html
- ***News Items***
- New Report Analyzes Options for Blending Hydrogen into Natural Gas Pipelines (March 14, 2013)
- Automotive Fuel Cell Cost and Durability Target Request For Information Issued (Feb 4, 2013)
- ***Monthly Newsletter***
- Visit the web site to register or to see archives (http://www1.eere.energy.gov/hydrogenandfuelcells/newsletter.html)

"Fuel cells are an important part of our energy portfolio…deployments in early markets are helping to drive innovations in fuel cell technologies across multiple applications."
- Dr. David Danielson
Assistant Secretary for Energy Efficiency and Renewable Energy


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

Fuel Cell Technologies Program

January 2012 Newsletter

Welcome to the inaugural issue of the Fuel Cell Technologies Program newsletter. This newsletter will be issued monthly to our Fuel Cell News subscribers and will include a recap of the previous month's news and events as well as a preview of upcoming activities.

In this issue:

- In the News
- Funding Opportunities
- Recent Blogs
- Webinars and Workshops
- Events Calendar
- Studies, Reports, and Publications

Hydrogen fuel cell powers lights at entertainment industry events.

Developed education materials and educated more than 9,600 teachers on H_2 and fuel cells to date.

Hydrogen fuel cell powered light tower at Space Shuttle launch

Funding Opportunity Announcements

U.S. DEPARTMENT OF ENERGY

Potential Technology Validation FOA Topics*

- Advanced refueling components (H_2 Meters, Dispensers, Compressors, Hydrogen Tank-Trailers).
- Hydrogen metering
- Rooftop systems for backup power units

- Notice of Intent – Issued week of May 6, 2013

Potential Manufacturing FOA Topics for FY 14

- Improved coating of electrodes
- High volume assembly processes
- Balance of Plant for PEM fuel cells and electrolyzers

* In conjunction with Market Transformation FOA

For More Information

U.S. DEPARTMENT OF ENERGY

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* On detail to FCTO while Antonio Ruiz is on extended leave of absence