PNNL-SA-117404

Demonstration of Fuel Cell Auxiliary Power Unit (APU) to Power Truck Refrigeration Units (TRUs) in Refrigerated Trucks

Kriston Brooks, PNNL (PM, Presenter)
Gus Block, Nuvera Fuel Cells
Todd Lutkauskas, ThermoKing

June 9, 2016

Project ID# MT014

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

- Timeline
  - Project Start: April 2013
  - Project End: Sept. 2017
  - Percent complete: 67%
- Budget
  - FY15 DOE Funding: $0K
  - FY16 Planned DOE Funding: $0k
  - Total DOE Project Value: $4M Total (PNNL) Program
    - Included $2M Micro-CHP project
    - Includes $1.5M for subcontracts
    - Contractor cost share $1.5M
- Barriers
  - C. Inadequate private funds available for infrastructure development
  - E. Lack of flexible, simple proven financing mechanisms
  - F. Inadequate user experience for fuel cell applications
- Partners
  - Project Lead
  - Fuel Cell Supplier/System Integrator
  - Transport Refrigeration Unit Developers
    - ThermoKing
  - System Demonstrators
    - H-E-B

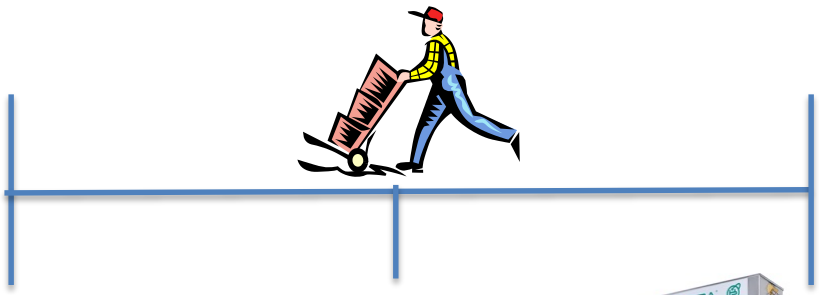
Relevance: Why a Fuel Cell Powered TRU?

TRU is a high-powered air conditioner used for transporting cold goods

- Environmentally-friendly technology system that addresses recent environmental mandates
  - "It's important to restaurants to run green trucks." "Our corporate definition of sustainability is to reduce fossil fuel use."
- Quiet operation that addresses noise restrictions in urban areas and may allow night-time operations
  - "We have been shut out of places because of noise."
- Energy-efficient compared to the incumbent internal combustion engine-powered vehicles
- Addresses diesel price uncertainty and the increasing availability of low cost natural gas and hydrogen
- Possible reduction in maintenance with fewer moving parts and less lubrication
- Lighter, more compact system to facilitate replacement of incumbent technology

Relevance: Where does it make most sense?

- "Hub and Spoke" Distribution Centers where single H_2 source can supply all vehicles
  - Return home each night to refuel
- Larger usage reduces hydrogen cost
- Hydrogen may already be on site for refueling fuel cell forklifts—safety issues addressed



Grocers and other Food Customers

Truck APU

H_2 Refueling

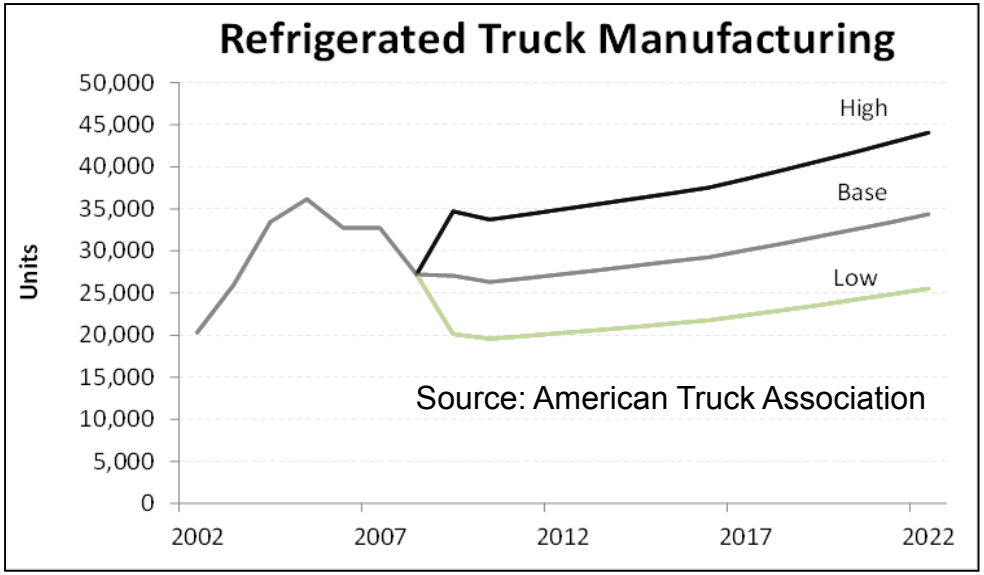
Fuel Cell Lift Truck

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

Relevance: How will fuel cell TRU's help the Hydrogen Infrastructure?

- U.S. fleet ~ 300,000 units
- Customer surveys show ~ 1:1 ratio of TRU to Material Handling Equipment (MHE) at distribution centers
- Potential near-term FC TRU market of 2,700 units, based on ARRA fuel cell MHE deployments in food industry



Multi-Temperature

20% of market

Single Temperature

80% of market

Pacific Northwest NATIONAL LABORATORY

Relevance: Project Purpose

Overall Objective: To demonstrate the viability of fuel cell-based Transport Refrigeration Units (TRUs) for refrigerated Class 8 trucks using demonstrations and business case development.

Barriers Addressed on This Project

C. Inadequate private funds available for infrastructure development

- Expand H_2 infrastructure where MHE already exists

E. Lack of flexible, simple proven financing mechanisms

- Provide DOE funding with 50% cost share to support the demonstrations

F. Inadequate user experience

- Developed safety plan to address operations and refueling
- Project involves the primary TRU company—ThermoKing
- TRU manufacturers involved in business case development

Pacific Northwest
NATIONAL LABORATORY

Approach

Deploy Fuel Cell TRU

Compete Subcontracts

NUVERA

Making hydrogen make sense.

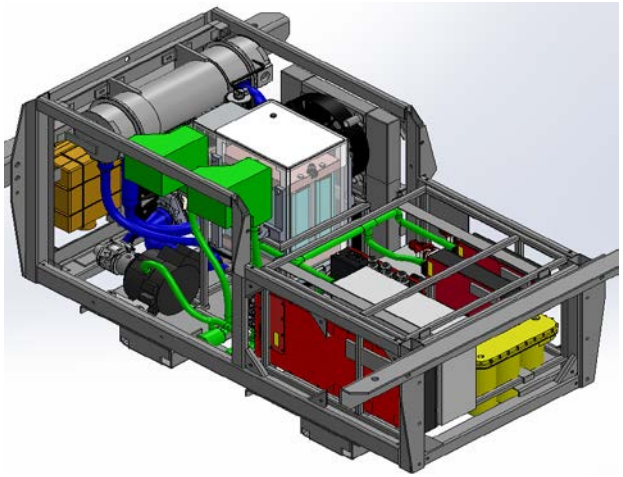
Second Demonstration: Decision Process Still Underway

Develop Business Case

With Investment Tax Credit				
Hydrogen	TRU Incremental Cost	Diesel $4.00	Diesel $6.00	Diesel $8.00
Hydrogen $2.50	$21,000	$ 21,888	$ 57,399	$ 92,980
Hydrogen $4.00	$21,000	$ 9,297	$ 44,878	$ 80,459
Hydrogen $6.00	$21,000	$ (21,990)	$ 13,592	$ 49,173
Hydrogen $8.00	$21,000	$ (53,276)	$ (17,695)	$ 17,887
Hydrogen $10.00	$21,000	$ (84,563)	$ (48,981)	$ (13,400)
Hydrogen $12.00	$21,000	$ (115,849)	$ (80,268)	$ (44,686)

Source: ThermoKing

Develop Fuel Cell "Reefer"



Source: Nuvera

Demonstrate 800-1000 hrs

Source: HEB

Approach

- Develop and demonstrate two fuel cell systems in commercial operations
- Assess the system performance
- Analyze its market viability

Nuvera: In 18 month project pause

2012-2013	2013-2014	2013-2014	2014-2015	2017	2017	Nuvera
2016	2016	2016	2017	2017	2018	TBD

Compete & Place Subcontracts → Develop Business Case → Size the System → Design & Test APU → 800-1000 hr Demo → Analyze Demo Results & Report

Acquire Fuel-Cell based system for demonstration:

- Acquisitions through open competition
- Team with manufacturers and end-users

Develop a business case:

- Voice of the customer
- Market assessment
- Value proposition analysis

Design the system:

- Develop fuel cell system with rated power
- Provide power conversion
- Address safety and compliant issues with TRU
- Make road-worthy
- Must be comparable to current diesel

Perform testing and demonstration:

- Site H_2 infrastructure preparation
- Perform intermediate tests: vibration, etc.
- Install system and commission APU
- Perform 800-1000 hour tests with actual deliveries and varying routes

Analyze Demo Results:

- PNNL will collect real time data and perform independent Technical / Economic Assessment
- Evaluate relative to DOE Technical Targets
- Update business case based on demonstration results
- Prepare final report

Demonstration Data Collection

Parameter		Purpose	Frequency
-GPS trace of path taken during demonstration -TRU operating hours		Characterize Demonstration	Daily
-TRU power demand -Fuel cell power output (kW) -Ambient temperature -Refrigerated container temperature -Fuel cell voltage (V) -Power used by electrical components -Time refrigerator door openings -State of charge of battery (batteries)		Technical Assessment	< 1 minute
-Fuel cell power output (kW) -Hydrogen mass inlet flow to fuel cell (SLPM) -Power used by electrical components		DOE Target: Fuel Cell Efficiency	< 1 minute
-Amount of fuel dispensed during refueling -Refueling rate (kg/min)		Technical/Economic Assessment	Per filling
-Start-up Time -Fuel Cell Temp	from 20^0C	DOE Target: Start-up Time	Per Start-up
	from standby		
-Mean time between component failures -Duration and number of maintenance shut downs -Cause of FCS shutdown		DOE Target: Operating Lifetime	Per failure/ By month

Milestones and Deliverables

Milestone Description	Owner	Milestone Type	% Complete	Notes
System Design and Verification	Nuvera	Standard	100% (Feb. 2015)	
Project Pause		**N/A**	N/A	**Feb. 2015 to Sept. 2016**
Complete Phase 2: System Development		Standard	Not started	**Feb. 2017**
Demonstration		**Go/No-Go**	Not started	**Apr. – Jun. 2017**

Milestone Description	Owner	Milestone Type	% Complete	Notes
Select Second Subcontractor			Underway	**May 2016**

Other Milestones Still under Negotiation

Summary of Accomplishments Since Last Annual Merit Review

- Nuvera
  - Further Refined Business Case
  - Performed Laboratory Demonstration
- Second Subcontract
  - Sent out Request for Proposal
  - Received Proposals
  - Proposals Under Evaluation

Nuvera/ThermoKing Example Value Proposition Analysis

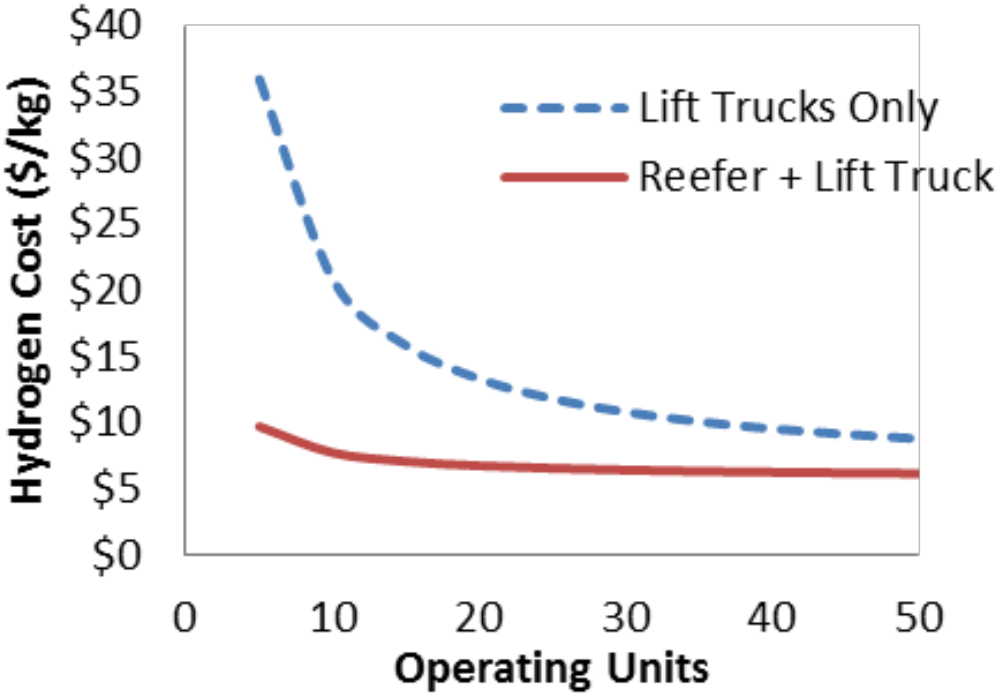
With Investment Tax Credit				
Hydrogen ($/kg)	**TRU Incremental Cost**	**Diesel $4.00 ($/gal)**	**Diesel $6.00 ($/gal)**	**Diesel $8.00 ($/gal)**
Hydrogen $2.50	$21,000	$ 21,888	$ 57,399	$ 92,980
Hydrogen $4.00	$21,000	$ 9,297	$ 44,878	$ 80,459
Hydrogen $6.00	$21,000	$ (21,990)	$ 13,592	$ 49,173
Hydrogen $8.00	$21,000	$ (53,276)	$ (17,695)	$ 17,887
Hydrogen $10.00	$21,000	$ (84,563)	$ (48,981)	$ (13,400)
Hydrogen $12.00	$21,000	$ (115,849)	$ (80,268)	$ (44,686)

"Tipping Point" between **positive**, **marginal**, and negative net present values depends on the cost of hydrogen and diesel.

20 kW fuel cell with 2X efficiency improvement over diesel
12 year trade cycle
2000 operating hours per year
Diesel ICE maintenance cost delta $3400
Federal tax credit 30% of fuel cell system cost, up to $3000/kW
H_2 price based on utility cost (gas, electricity, water) of on-site generation

Estimated Reduction in Diesel Usage and Hydrogen Cost

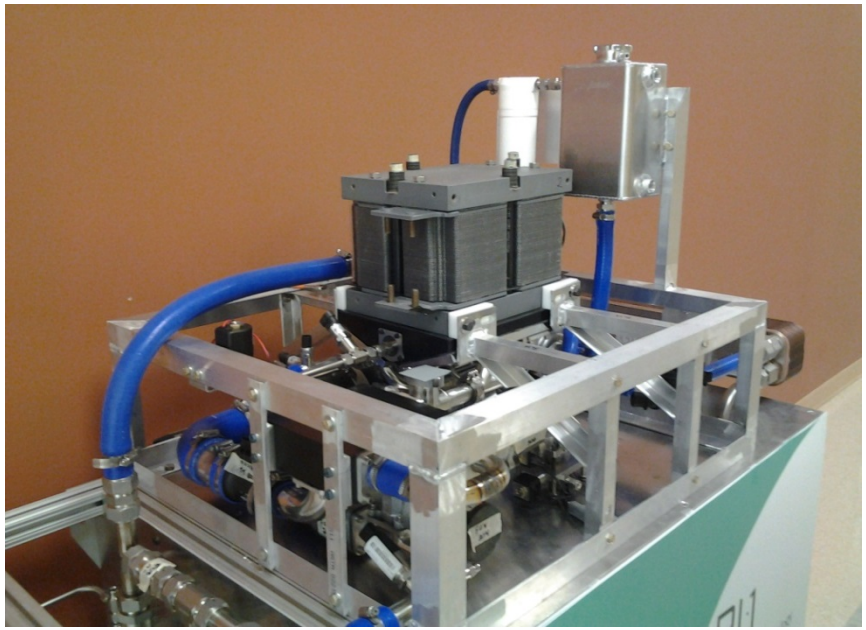
- 8 gallons/day diesel vs. 10 kg/day H_2
- 10 hours/day
- 2900 gal/year diesel savings
- 1:1 ratio reefer to lift truck yields 6 fold increase in H_2 usage
- Significant reduction in hydrogen cost with increased usage



Nuvera Team Demonstration Progress

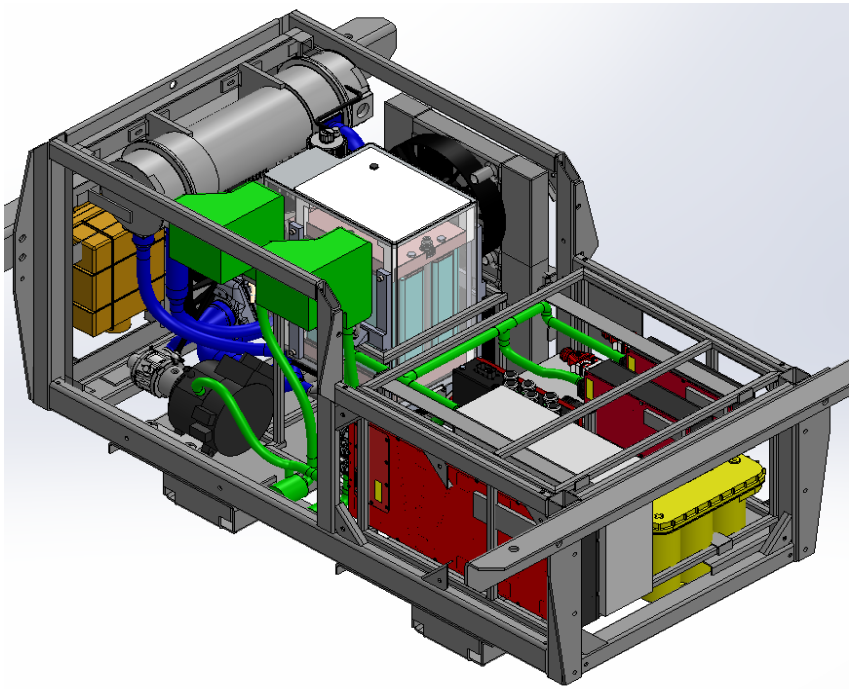
Developed Test Stand

- 20+ kW output
- Performed polarization curve



Developed Preliminary Design

- System under-mounted to trailer
- FC system packaged in ThermoKing generator frame



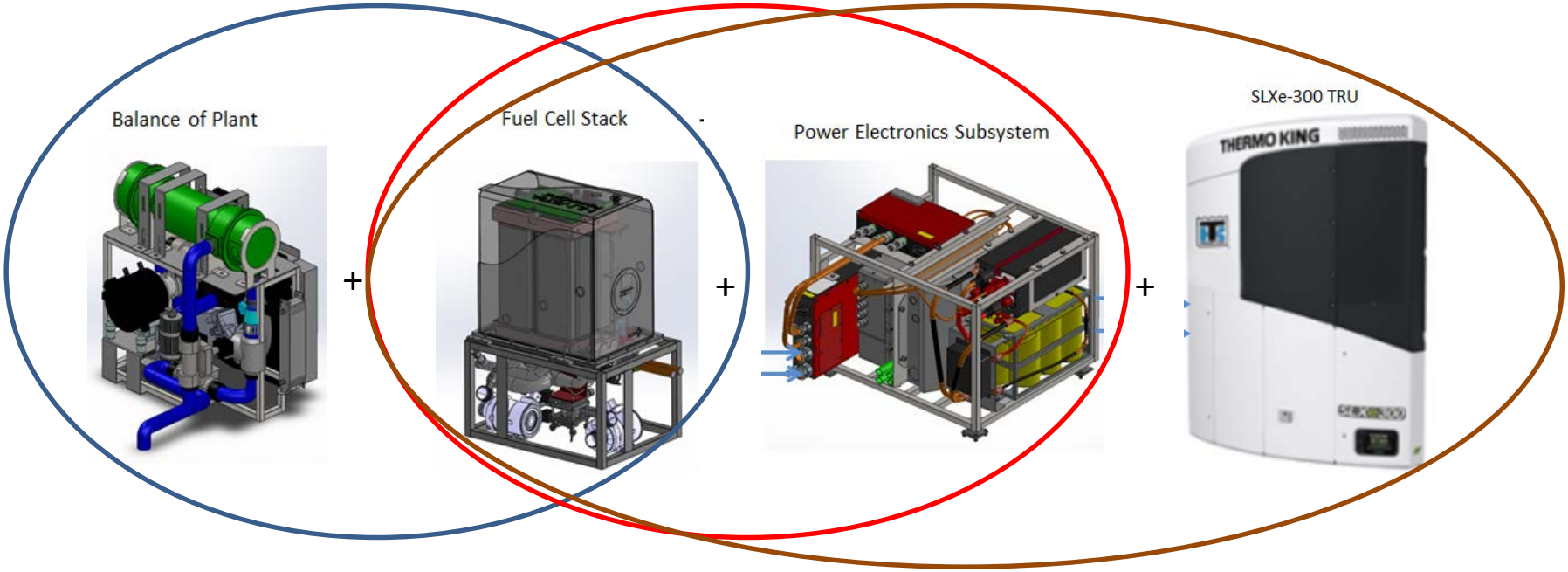
Significant progress has been made to develop a system design that can address on-road deployment

Nuvera Testing of Integrated Fuel Cell System with TRU

Demonstration 1
3 hours, 28 kWe DC

Demonstration 2
2.5 hours, 21 kWe AC

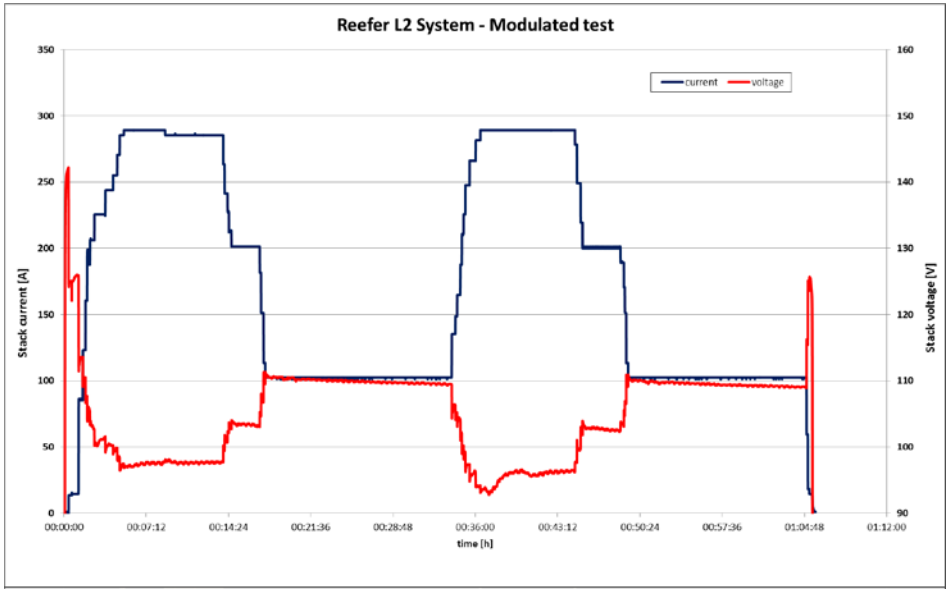
Demonstration 3
4 hours, 9 kWe AC

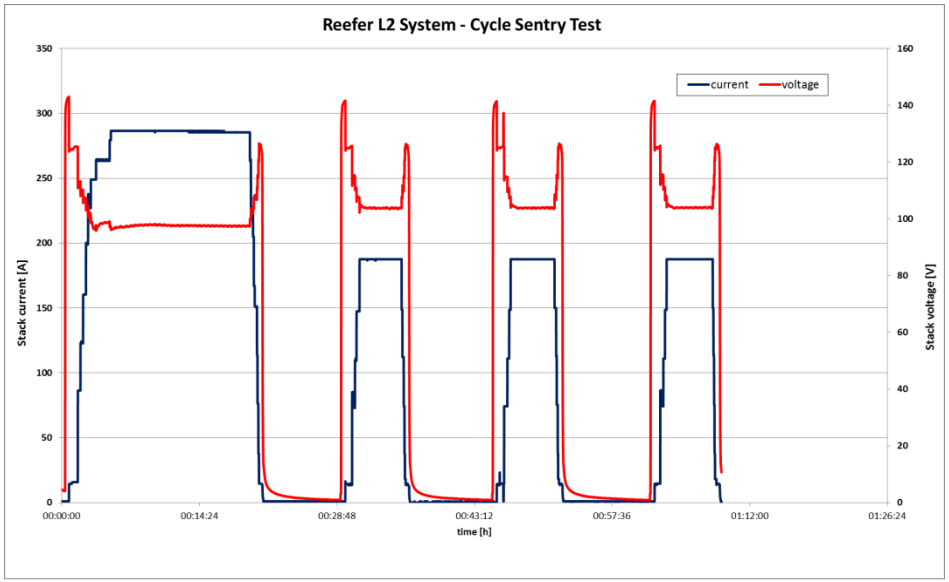


All components have been tested but entire system has not yet been integrated

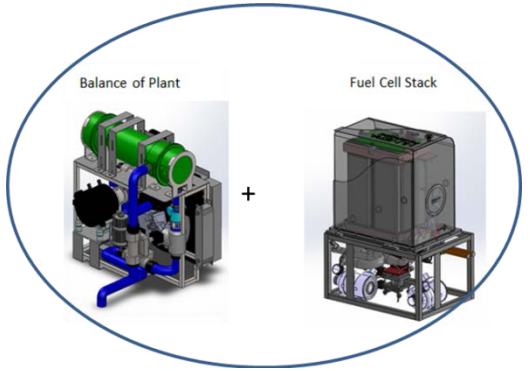
Pacific Northwest
NATIONAL LABORATORY

Nuvera Demonstration 1





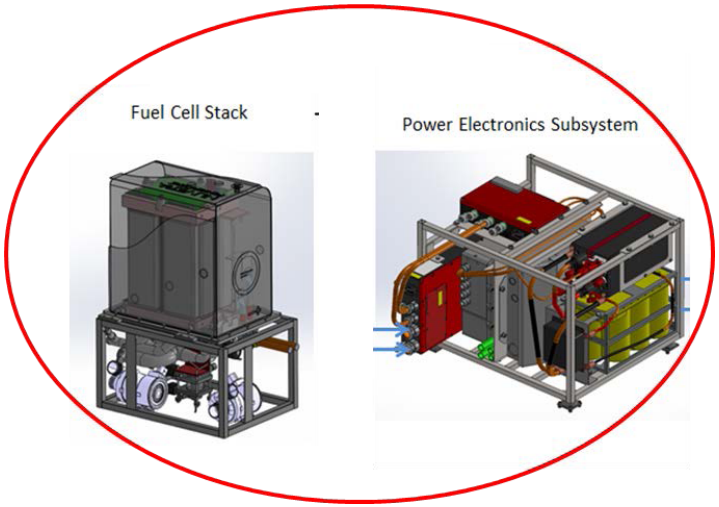
Fuel Cell and Balance of Plant have been tested in two operating modes



- Fuel Cell Stack coupled with prototypic balance of plant components
- Tested Modulated (varied power)
- Tested Sentry Cycle (on/off)

Nuvera Demonstration 2

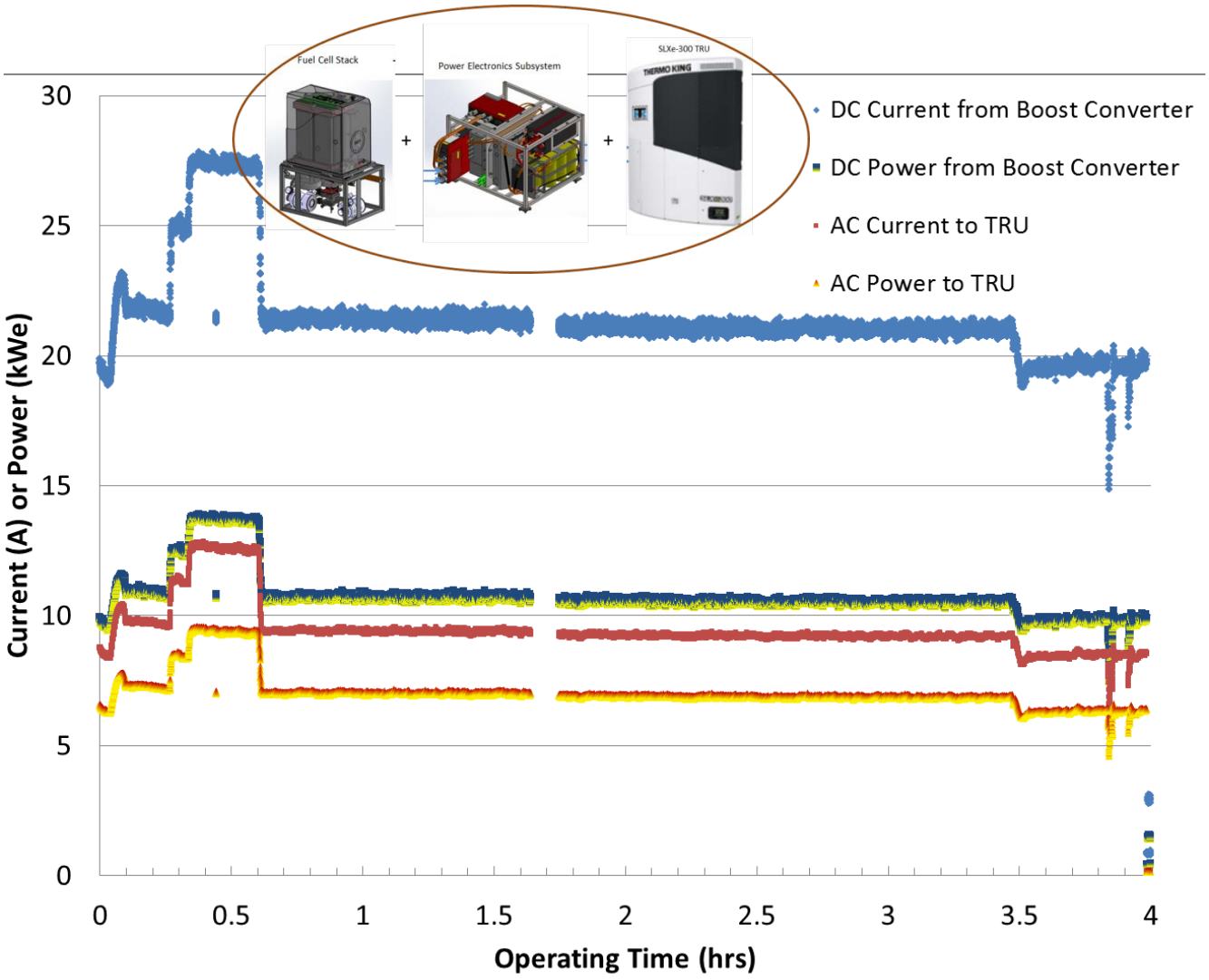
- System is required to produce 17 kWe 3 Phase AC power
- Fuel Cell Stack integrated with power electronics
- Used non-prototypical balance of plant
- Power dissipated with induction motor and brake load
- Operated for 2.5 hours



Fuel Cell Stack and Power Electronics Demonstrated up to 21 kWe of 3 Phase AC Power

Nuvera Demonstration 3

- Fuel Cell Stack coupled with power electronics and SLXe-300 TRU
- Non-prototypic BOP
- Maximum power 9 kWe
- Tested for 4 hours



Fuel Cell Integrated with a lower power TRU

Responses to Previous Year Reviewer's Comments

FY14 Reviewer Comment	FY16 Response to Comment
"The potential impact is huge ***if*** there is a business case, given the number of reefer trucks on the road and the number sold each year."	Contractors are required to develop a business case early in the project prior to a Go/No-Go and then develop a commercialization plan after the demonstration.
"The approach is sound but as always, the cycle time to get these types of items ready for market introduction could and should be accelerated."	The recent RFP included verbiage: "Proposers will score more favorably if their schedule exhibits the offeror's ability to complete the demonstration sooner."
"The reason for the 400-hour demonstration was not defined in the slides."	The DOE Target for Degradation is based on 1000 hrs of operation. As a result, the recent RFP was extended to 1000 hrs.
"The demonstration and analysis aspect of this project was not discussed as much as expected."	The specific parameters that will be taken from the demonstration and their purpose are included in this presentation.

Collaborations

Partner		Project Roles
DOE		Sponsorship, Steering
PNNL		Project Lead, Manage Subcontracts, Analysis of Demonstration Data, Assist in Business Case Development
Nuvera	TBD	Fuel Cell Supplier, System Integrator
ThermoKing	TBD	Integration of APU with TRU
ThermoKing	TBD	Business Case Development
HEB	TBD	Demonstration Partner

- Special Thanks
  - Pete Devlin, DOE-EERE Fuel Cells Technology Office

Pacific Northwest
NATIONAL LABORATORY

Remaining Challenges and Barriers

- Develop and demonstrate a robust fuel cell based APU for commercial TRUs that:
  - Is capable of on-road operation
  - Meets the cost targets that make it economically viable
  - Can be integrated into existing TRU design
  - Meets or exceeds the operation requirements of the existing diesel engine
  - Can be refueled easily and economically
- Generate the required interest to drive the system to market

Future Work for Upcoming Year

- PNNL
  - Ensure high quality work performed to meet milestones
  - Identify other value propositions
  - Collect and analyze data from demonstrations
- Nuvera Team
  - Finalize TRU System for On-Road Application
  - Perform 2- 400 hour demonstrations at HEB
- New Demonstration Team
  - Develop business case
  - Design system and complete safety documentation
  - Develop system
    - Sized appropriately
    - Robust system for on-road application

Technology Transfer Activities

- Share Results
  - Press Releases, Interviews, Presentations, Publications
- Develop Business Cases and Commercialization Plans
  - Working with largest TRU manufacturers in the U.S.
  - Working with potential customers for demonstrations
- Look for Potential Future Funding for Follow-On Demonstrations

Project Summary

Relevance	Demonstrate the technical and commercial viability of fuel cell-based Transport Refrigeration Units (TRUs) for refrigerated Class 8 trailers.
Approach	• Demonstrate fuel cell system in commercial applications • Assess the system performance • Analyze its market viability
Technical Accomplishments and Progress	• Updated ThermoKing Business Case • Demonstrated integrated system performance in the laboratory • Subcontract process underway for second demonstration
Collaborations	• Nuvera and its team: ThermoKing, H-E-B, Air Products • New Demonstration Team
Proposed Future Research	• Continue to oversee project • Perform multiple demonstrations and analyze results

Project ID# MT014

Kriston Brooks
(509) 372-4343
kriston.brooks@pnnl.gov

Questions?

Contact:

Kriston P Brooks ☎: 509-372-4343 ✉: kriston.brooks@pnnl.gov