Fuel Cell Based Auxiliary Power Unit for Refrigerated Trucks

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Project ID# MT014

Overview

- Timeline
  - Project Start: April 2013
  - Project End: Dec. 2015
  - Percent complete: 37%
- Budget
  - FY13 DOE Funding: $800k
  - Planned FY14 DOE Funding: $0k
  - Total DOE Project Value: $1.6M Total (PNNL) Program
    - Includes $1.3M for subcontracts
    - Contractor cost share $1.6M
- Barriers
  - E. Inadequate private funds available for new projects
  - F. Inadequate user experience for fuel cell applications
  - H. Lack of awareness of applications
- Partners
  - Project Lead
  - System Integrators
  - Transport Refrigeration Unit Developers
    - ThermoKing
    - Carrier Transicold
  - System Demonstrators
    - HEB and Sysco
  - H_2 Provider: Air Products

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NUVERA Making hydrogen make sense.

plug power FUEL CELL SYSTEMS

Relevance

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

Barriers Addressed This Reporting Period

E. A lack of financing mechanisms: Inadequate private funds available for new projects

- Provide DOE funding to support the demonstrations
- Developed system design and performed prototype testing

F. Inadequate user experience

- Developed safety plan to address operations and refueling
- Developed business case to determine commercial feasibility

H. Industry stakeholder lack of awareness of applications

- Project involves the two primary TRU companies—ThermoKing and Carrier Transicold
- TRU manufacturers involved in business case development

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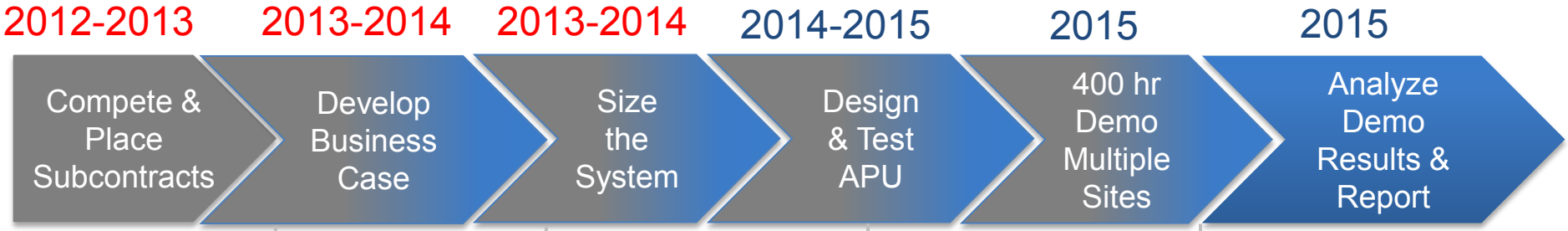
Value Proposition for a Fuel Cell Based Auxiliary Power Unit for Refrigerated Truck

- Fuel cells system replaces diesel engine in providing power to the Transport Refrigeration Unit (TRU) resulting in a system that:
  - Is an environmentally-friendly technology system that addresses recent environmental mandates
  - Has quiet operation that addresses noise restrictions in urban areas and may allow night-time operations
  - Is cost-competitive and more energy-efficient compared to the incumbent internal combustion engine-powered vehicles
  - Addresses the uncertainty of diesel prices and the increasing availability of low cost natural gas and hydrogen
  - Ultimately shows decreased energy expenditures when compared to diesel-powered TRUs

Approach

- Two year program to develop and demonstrate fuel cell system in commercial operations
- Assess the system performance
- Analyze its market viability



Acquire Fuel-Cell based system for demonstration:

- Acquisitions through open competition
- United States companies solicited
- Team of manufacturers and end-users

Develop a business case:

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

Define the power rating of the system:

- Must be comparable to current diesel
- Model expected door openings and ambient temperatures
- Collect actual experimental power profiles

Design the system:

- Develop fuel cell system with rated power
- Provide power conversion
- Address safety and compliant issues with TRU
- Make road-worthy

Perform testing and demonstration:

- Site H_2 infrastructure preparation
- Perform intermediate tests: vibration, etc.
- Install system and commission APU
- Perform multiple 400 hour tests with actual deliveries and varying routes

Approach

Deploy Fuel Cell TRU

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

Compete Subcontracts

Source: Nuvera

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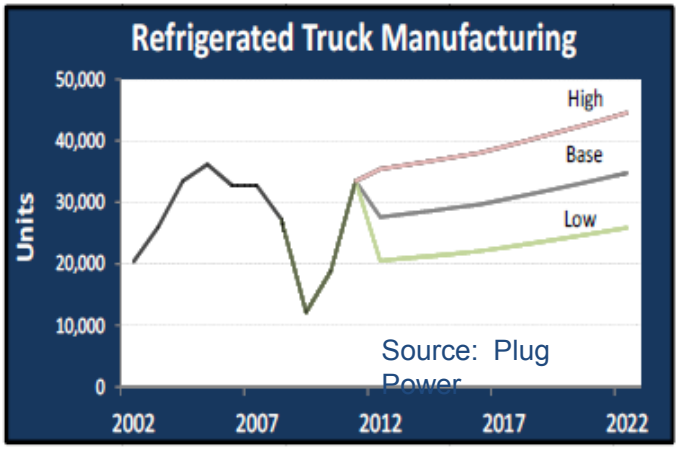
Making hydrogen make sense.

Source: Plug Power

plug power

Develop Business Case



Source: Plug Power

Develop Fuel Cell "Reefer"

Source: Plug Power

Demonstrate > 400 hrs at 3-4 Sites

Source: Nuvera

Planned Demonstrations

- Nuvera
  - Developing one system
  - Developing APU for Single Temperature Trailer
  - Performing two 400-hour demonstrations with HEB
  - Sysco is still interested, but do not use single temp trailers

- Plug Power
  - Developing three systems
  - Developing APU for Multi-Temperature Trailer
  - Performing four 400 hour demonstrations with Sysco

Approach

Milestones and Deliverables

Milestone Description	Owner	Milestone Type	% Complete	Notes
Develop Business Case	Nuvera	Go/No-Go	100% (Sept 2013)	DOE gave a "Go" decision
Develop Safety Plan	Nuvera Plug Power	Standard	On-Going Improvements	Safety Plan reviewed by Hydrogen Safety Panel
Subsystem Testing	Nuvera	Standard	100% (April 2014)	
Lab Scale Prototype Testing	Plug Power	Standard	100% (April 2014)	
Successful Test of Alpha Prototype	Plug Power	**Go/No-Go**	Underway	**Due Date May 2014**
System Design and Verification	Nuvera	Standard	Underway	**Due Date June 2014**
Demonstration	Nuvera	**Go/No-Go**	Not started	**Nov-Mar 2015**
Demonstration	Plug Power	**Go/No-Go**	Not started	**May-Sept 2015**

Summary of Accomplishments This Year

- Set up subcontracts
- Developed business case
- Defined power requirements
- Addressed interfaces
  - Refueling and electrical connections
- Prepared initial design documents
  - Prepared safety plan included such things as ISV, PrHA, DFMEA
- Performed initial system testing
- Developed preliminary design

Developed Business Case

- Approach
  - Identify key value drivers
  - Voice of the Customer
    - Interviews with maintenance, engineers, warehouse, managers
    - Identified customer's needs
  - Value Proposition Analysis
    - Cost of hydrogen vs. cost of diesel vs. cost of TRU
    - Positive vs. negative net present value
    - Payback period
- Results
  - Most of the results are considered proprietary
  - Positive NPV and < 2 years payback possible
  - Large fleet required to bring down H_2 price

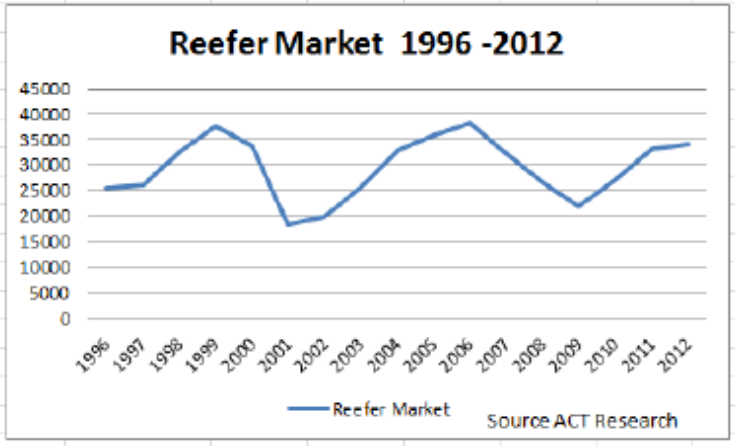
Accomplishments

Nuvera/ThermoKing Business Case

Sample Voice of the Customer

Customer Need	Comments and Insights from Interviews
Ensure and Acceptable ROI	"ROI is the biggest driver after safety." Commercial Product must ultimately be cost-effective on a life-cycle cost basis.
Achieve Sustainability Goals	Being a sustainability leader in the industry is critical to corporate image, due to expectations of consumers. "It's important to restaurants to run green trucks." "Our corporate definition of sustainability is to reduce fossil fuel use." Water consumption is also an issue. Sustainability generally includes long-term economic feasibility of proposed solutions.
Reduce Noise Pollution	Noise from diesel engines is unacceptable in an increasing number of settings where food is delivered, including densely residential areas, underground parking, hotels, hospitals, and nursing homes. In some cases noise is specially regulated by local ordinances. "We have been shut out of places because of noise."

Market Assessment

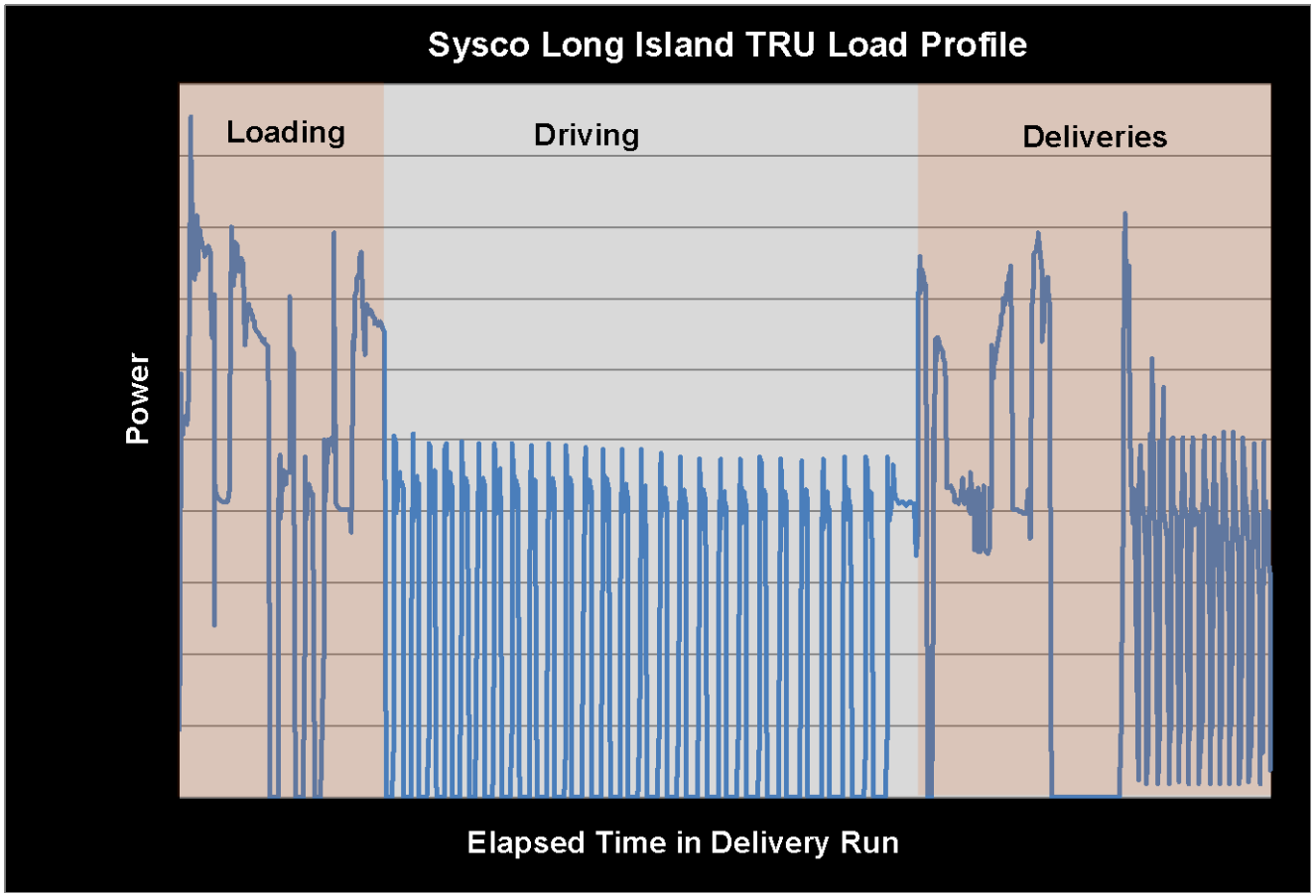


Sample Value Proposition Analysis

		With ITC		
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)

Defined Power Requirements

- Plug Power: Data logging at Long Island compared to previous testing at Sysco Houston



Addressed Interfaces

Hydrogen Supply

~10 kg dispensed to TRU at 350 bar

Interconnect Strategy

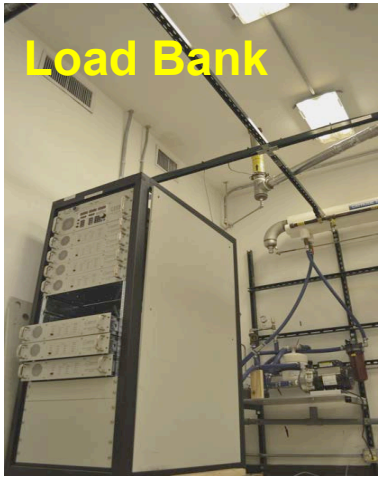
Power leads can be run to the electric input that already exists.

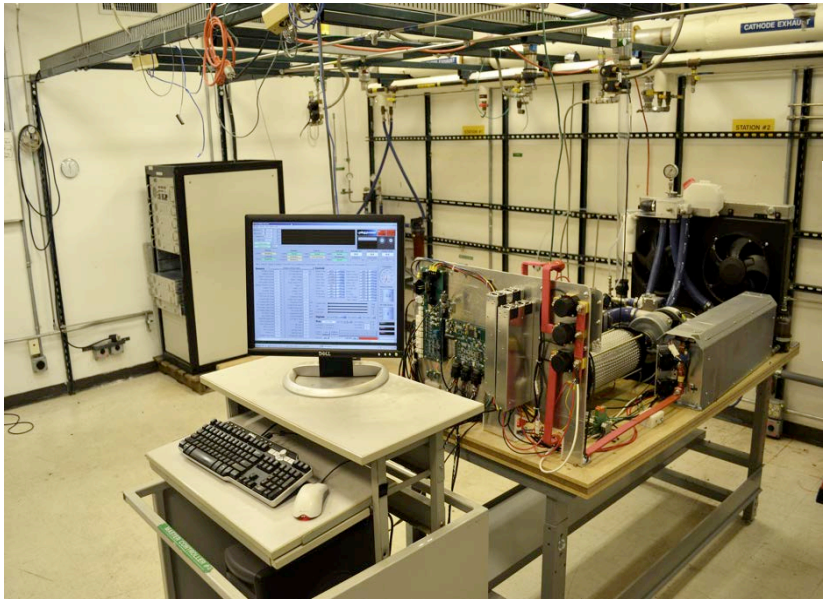
Instead of trying to fit a fuel cell into the TRU envelope for the demo, it makes more sense to use the electric standby option on the TRU.

The DG acts as a backup. If there is an issue with the fuel cell, the TRU controls automatically switch the power input to the DG.

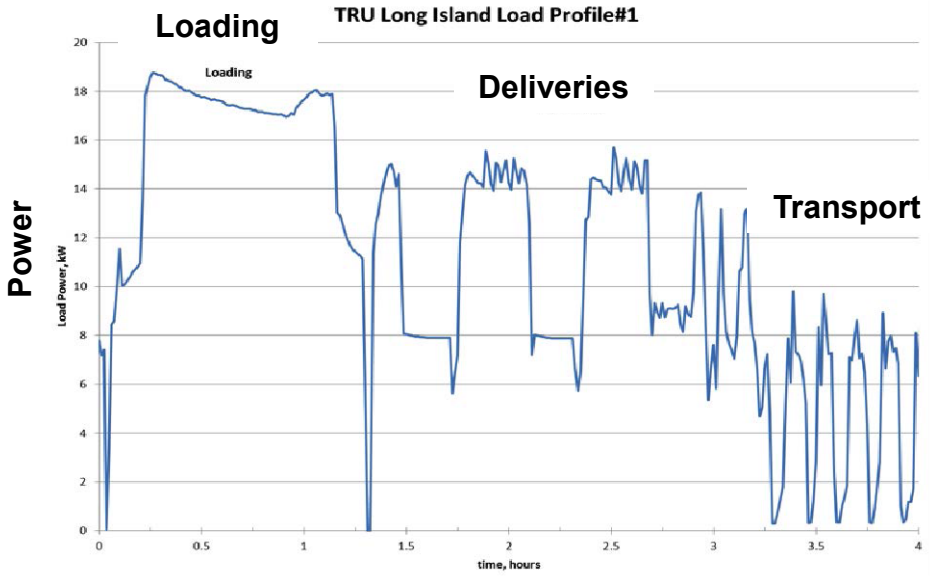
Plug Power: Completed Alpha Prototype Testing

- 20+ kW output
- 35 kW thermal rejection
- Cold temp testing - freeze protection
- High temp testing - stack cooling margin
- Performs well against application load profile



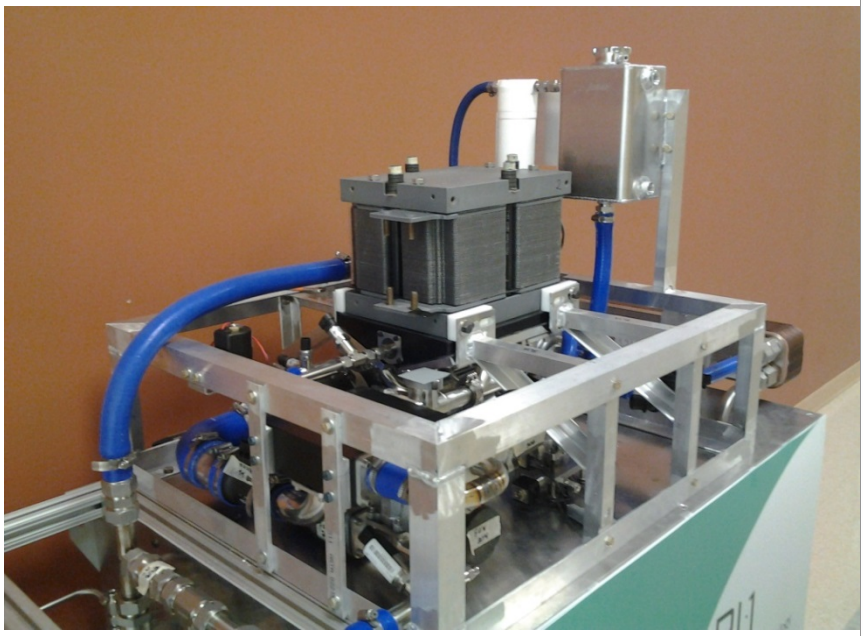


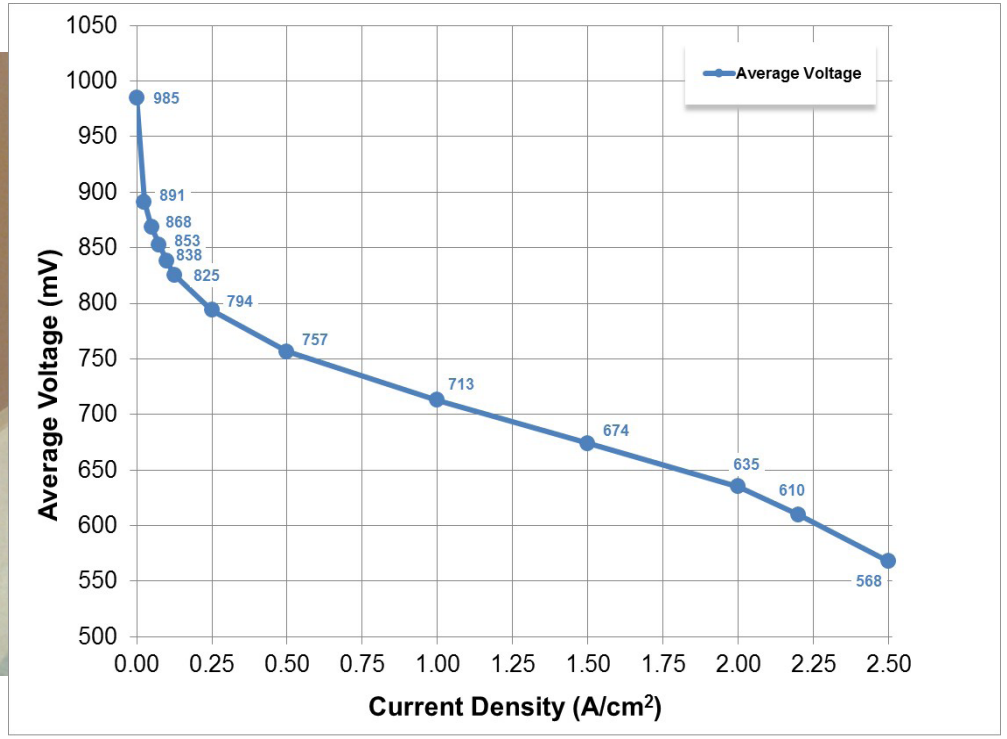
TRU Prototype



Nuvera: Completed Level 1 Prototype Testing

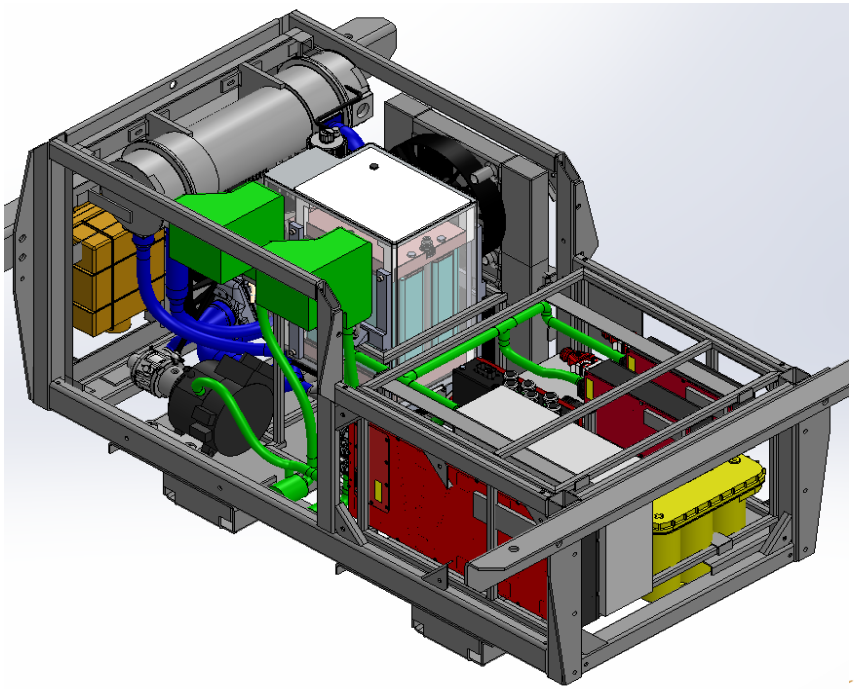
- **Developed PI1 Test Stand**
- **Tested SmartStack™ controls logic**
- **20+ kW output**
- **Performed polarization curve**





Developed Preliminary Design

- FC System will be packaged in SGCM3000 frame (ThermoKing's generator)



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Responses to Previous Year Reviewer's Comments

- Not Applicable: First Year Presentation

Collaborations

- Nuvera Team
  - Nuvera
    - Fuel Cell Supplier
    - System Integrator
  - ThermoKing/Ingersoll Rand
    - Business Case Development
    - Integration of APU with TRU
  - HEB and Sysco
    - Demonstration Partners
- Plug Power Team
  - Plug Power
    - System Integrator
  - Carrier/Transicold
    - Integration of APU with TRU
  - Sysco
    - Demonstration Partner
  - Air Products
    - Hydrogen Refueling Station

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

Remaining Challenges and Barriers

- Develop 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

Future Work for Upcoming Year

- PNNL Manage Subcontracts
  - Ensure high quality work performed to meet milestones
  - Identify other value propositions

- Nuvera and Plug Power Team
  - Develop and test full prototype system
  - Finalize infrastructure changes
  - Certify for On-Road Application

Project Summary

Relevance	Demonstrate the 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	• Developed business cases and safety plans • Developed system designs and addressed interfaces and H_2 infrastructure issues • Successfully demonstration subsystem performance
Collaborations	• Nuvera and its team: ThermoKing, Sysco, and HEB • Plug Power and its team: Carrier Transicold, Sysco and Air Products
Proposed Future Research	• Continue to oversee project • Complete system design and testing • Perform multiple 400 hour demonstrations

Project ID# MT014

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Technical Backup Slides

Timeline of Approach

Task				FY14				FY15				FY16			
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Nuvera															
Contract Signed															
Develop Business Case															
Develop Preliminary Safety Plan															
Go/No-Go #1															
Complete PrHA and ISV															
Preliminary Design															
Detailed Design															
Stack Core Testing															
Subsystem Testing															
Fuel Cell System Testing															
Fuel Cell /TRU Integration															
Go/No-Go #2															
Demonstrations															
Final Report															
Plug Power															
Contract Signed															
System Requirements Document															
Develop Preliminary Safety Plan															
Develop Load Profile															
Prototype Build and Testing															
Go/No-Go #1															
Complete Build of 3 Systems															
Factory Acceptance Testing															
OEM Testing															
Go/No-Go #2															
Commisioning on Truck															
Demonstration															
Final Report															