Zero-Emission Cargo Transport II: San Pedro Bay Ports Hybrid & Fuel Cell Electric Vehicle Project

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Project Overview

Timeline

- Project Award: 10/1/14
- Contractor Kickoff: 12/16/15
- Project Completion: 9/30/19

Contractors & Projects

- BAE/CTE: Fuel cell range extended drayage truck
- TransPower: Fuel cell range extended drayage truck
- U.S. Hybrid: Fuel cell powered drayage truck
- Hydrogenics: Fuel cell range extended drayage truck
- BAE/GTI: CNG hybrid with Near Zero CNG Engine

Barriers & Challenges

- Fueling Infrastructure: Availability and location
- Costs: Fuel Cells, batteries and infrastructure
- System Integration: Safe and efficient deployment of the technology Barriers & Challenges

Budget

- DoE: $10,000,000
- Funding partners: $7,467,473
- Contractors: $3,075,841
- Total Cost:$20,543,314

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Relevance: Goals & Objectives

2018/2019 Objectives

- Complete vehicle builds
- Operate portable hydrogen refueling for demonstration
- Begin vehicle demonstration and data collection

Results

- First deployment began from Q2 2018 with two fuel cell range extended trucks
- Portable hydrogen fuel onsite is in operation
- Debugging and design improvement are in progress by lessons-learned from the first demo trucks

Impact

- Pushing Zero Emission Technology and Industry Envelope by Demonstrating First Fleet of FCEV's in Drayage Service in California

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Remaining Challenges & Barriers

Fueling Infrastructure - Availability and location

- All temporary hydrogen fueling is in place and being used for the demonstration
- Permanent stations will be a challenge – SCAQMD is working with partners on a solution (Renewable hydrogen station, ZANZEFF project)

System Integration: Safe and efficient deployment of the technology

- Six of seven vehicle designs and integration are complete including CNG hybrid truck
- Design improvement and system optimization
- Analyze data collected and secure reliability

Costs and Application

- Costs will remain a challenge for the near and mid term
- Penetration into mid or long range application

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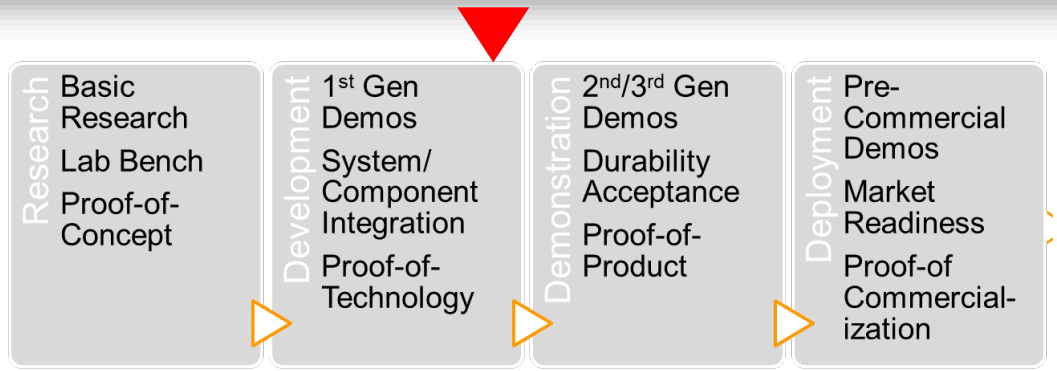
Approach



	FUEL CELL TRUCKS				PHET/CNG
	TransPower	Hydrogenics	US Hybrid	BAE/Kenworth	
# of Vehicles	2	1	2	1	1
Platform	International	Freightliner	Kenworth T800	Kenworth T370	Kenworth T680
Mfg: Fuel Cell / APU	Hydrogenics	Hydrogenics	PureMotion	Ballard	CWI L9N NZE
Fuel Cell Power	60 kW	60 kW	80 kW	85 kW	n/a
Battery Capacity	125 kWh	100 kWh	26 kWh	100 kWh	100 kWh
Battery Chemistry	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion
Traction Motors	2x 150 kW	1x 320 kW	1x 320 kW	1x 420 kW	1x 420 kW
Range (per fueling)	200 miles	150 miles	150-200 miles	112 miles	150 miles
Fuel Cap.: H2 (kg) / CNG (DGE)	27 kg @350 bar	30 kg @350 bar	20 kg @350 bar	30 kg @350 bar	45 DGE

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Technical Progress – Hydrogen Stations

Portable hydrogen refueling at Kenworth test site (Mt. Vernon, WA) and Port of LA demonstration site (San Pedro, CA)

- Air Products supports both fueling stations
- San Pedro equipment will remain active throughout the vehicle demonstration period for all vehicles under this program
- San Pedro site features 2x Air Products HF-150 mobile refuelers:
  - Capacity: ~300 kg/day
  - Pressure: 350 bar

Photo: Kenworth

Mobile Refueler – Mt. Vernon

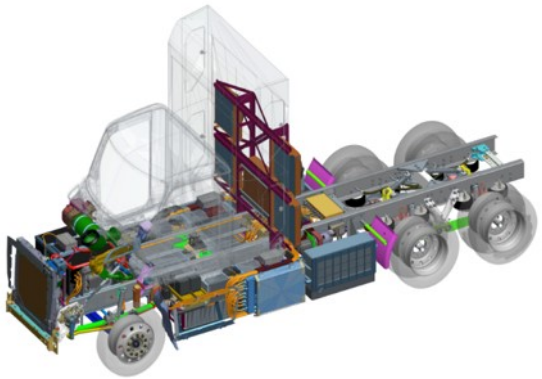
Mobile Refueler – San Pedro

Photo: CTE

Technical Progress – Fuel Cell Truck

Phase 1: Vehicle Development

- Project Management for Phase 1 – Complete
- Establish Contracts – Complete
- Define Master Project Plan for Subcontractors – Complete
- Vehicle System Design – Complete
- Long Lead Items Procurement – Complete
- Secure Hydrogen Fuel Supply for Contractor Testing – Complete
- Lab Integration of the Sub-System Components – Complete
- Vehicle Mechanical Integration – Complete
- Secure Hydrogen Fuel Supply for SCAQMD Program Demonstration – Complete
- Vehicle Electrical Integration – Complete



Fuel cell truck packaging layout

Completed vehicle integration

Technical Progress – Fuel Cell Truck

Phase 1: Vehicle Development

- **Vehicle Testing and Validation – estimated 99% Complete**
  - ✓ Kenworth completed track testing, road trials, system tuning and assigned the VIN
  - ✓ The vehicle was delivered to the operator, TTSI, at the Port of LA on February 4th, 2019
  - ✓ Kenworth will prepare and submit the vehicle performance test results including all parameters listed in the statement of work

climbing 30% slope at 80,000 GVW

Parameter	Target	Measured
Range Total	112 miles	216 miles
Elec-Only	n/a	27 miles
Top Speed	70 mph	70 mph
Grade-ability Speed 6.5 %	35 mph	36 mph
Speed 5.0%	40 mph	40 mph

- Note: 65,000 lbs. GCW
- Vehicle completed 3,300 of road and track miles before delivery to TTSI

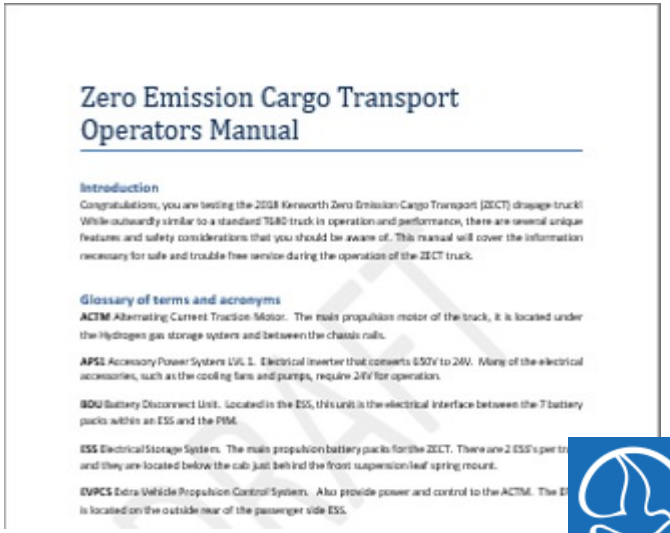
Technical Progress – Fuel Cell Truck

Phase 2: Demonstration and Data Collection

- **Project Management for Phase 2 (Demonstration and Data Collection) – Estimated 4% Complete**
  - ✓ Phase 2 will detail demonstration support and data collection activities conducted by the project team

- **Vehicle In-Service Operation and Data Collection – estimated 4% Complete**
  - ✓ Kenworth conducted training for TTSI operators and maintenance staff as well as local First Responders.
  - ✓ Internal maintenance and safety training were also conducted at the Kenworth dealership in Carson, CA.
  - ✓ Ballard provides on-site supports for fuel cell diagnostics and service activity at the Kenworth dealership
  - ✓ Kenworth and BAE will support the vehicle during operation at the Port of LA. This includes collecting and analyzing performance data.

Fuel Cell truck is delivered at TTSI



Zero Emission Cargo Transport
Operators Manual

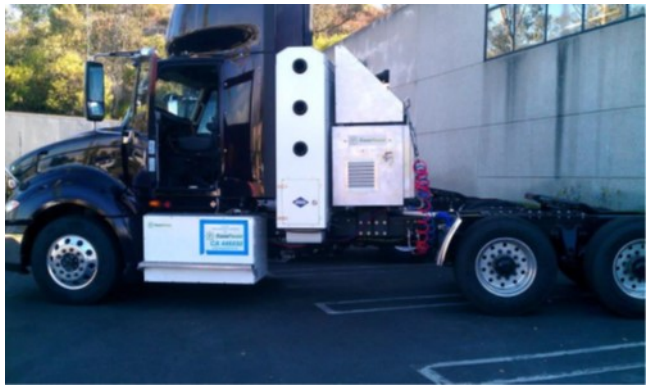
Introduction

Glossary of terms and acronyms

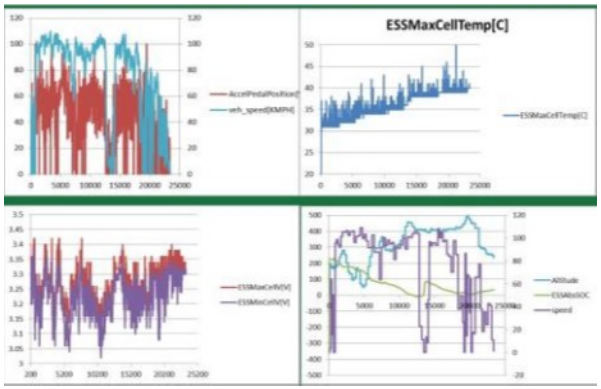
Operator Manual

Demonstration of Fuel Cell Truck #1

- Fuel Cell Truck #1 has been deployed at TTSI, Q2 2018FC1
- Data has been collected while demonstration
- The truck has not been operated due to intermittent drive train issues
- Transferred to the TransPower integration facility to perform various inspections and troubleshoot intermittent faults
- 500 – 1000 miles of drive testing for continue error proofing of vehicle.



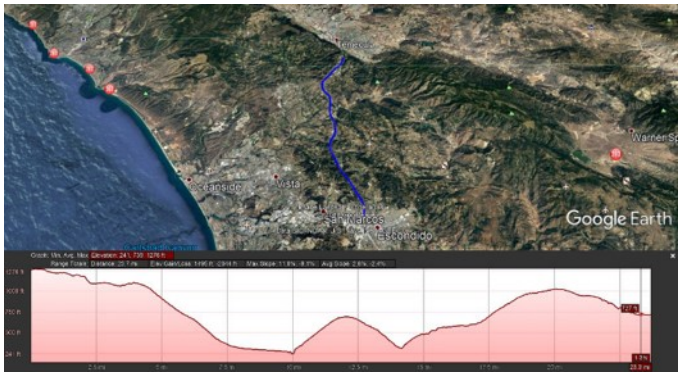
Recommissioning of Fuel Cell Truck #1



2 hours of data, driving from Escondido to Riverside

Development of Fuel Cell Truck #2

- Complete integration
- Multiple causes of faults have been addressed
- Full load driving from Escondido to Temecula has been tested
  - ✓ Continuing to evaluate drivability and reliability
  - ✓ Continued evaluation of fuel consumption and range for trips of 100 miles and more
- The vehicle will be deployed when low level faults are resolved



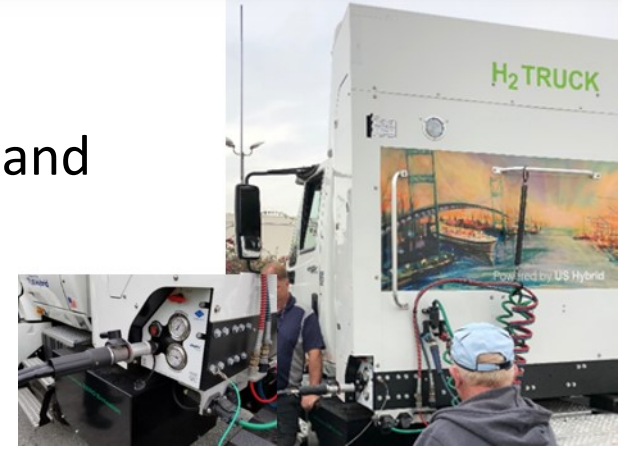
Test driving of 45 miles round trip with 900m elevation gain

Complete integration of Fuel Cell Truck #2

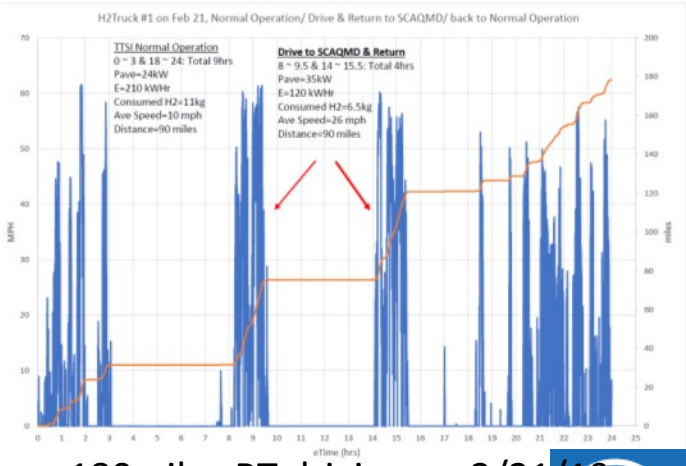
Technical Progress – Fuel Cell Truck

Demonstration of Fuel Cell Truck #1

- US Hybrid's first fuel cell truck has been deployed and demonstrated at TTSI
- **H_2Truck Curb Weight 16,000 lbs** (comparable to Diesel)
- **GVWR 80,000 lbs.**
- **Summary of a day of operation**
  - ✓ Operation hours – 3.3
  - ✓ 8.4 miles/kg-H_2
  - ✓ kWh – 116.0 (CSA) / 108.8 (Net FC Engine, including dc-dc)
  - ✓ H_2 flow in – 6.31 kg (Fueling data)
  - ✓ H_2 consumed – 5.99 kg (FCe™80 reporting)
  - ✓ CSA kWh/kg – 18.4
  - ✓ >17.3 kWh/kg (Net FC Engine, including Isolated dc-dc)



Fuel Cell Truck #1 in demonstration



180miles RT driving on 2/21/19

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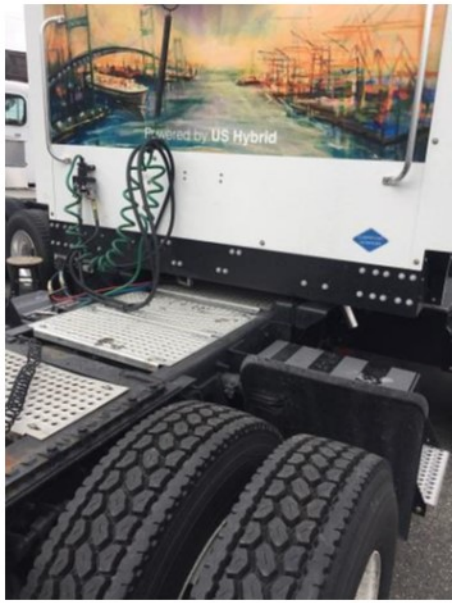
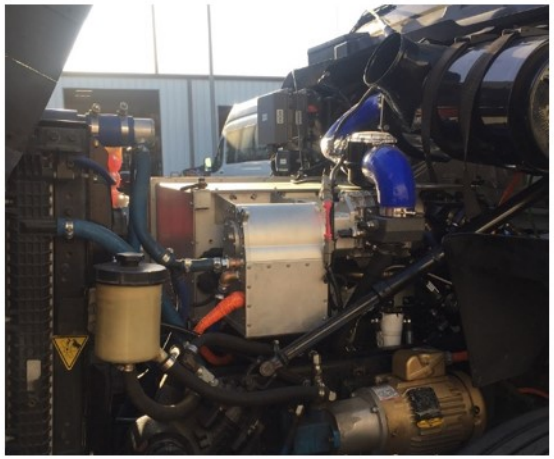
Technical Progress – Fuel Cell Truck

Development of Fuel Cell Truck #2

- Battery system upgraded with Liquid cooling
- Air filter system upgraded.
- Truck Auxiliary/cooling loads reduction by 20%.
- Truck steps customized per Operator request.



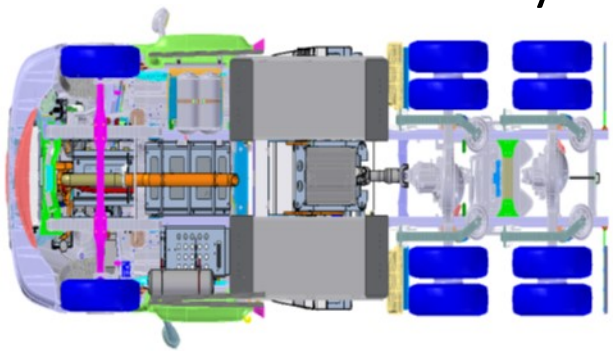


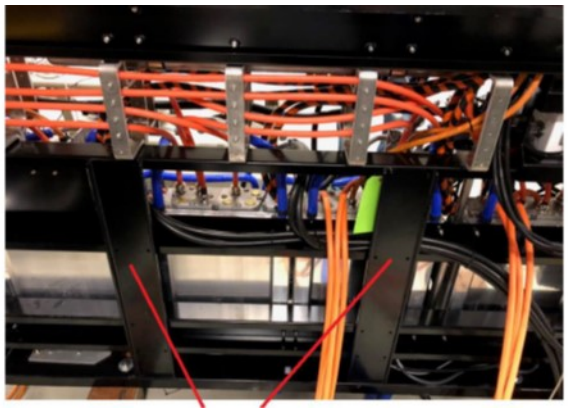
Complete integration of Fuel Cell Truck #2

Technical Progress – Fuel Cell Truck

Development of Fuel Cell Truck

- Fuel Cell System & Cradle is installed including final air intake and filter mounting and external hydrogen sensors mounted
- Battery System is mounted and tested
- Siemens cradle and main drive motor coolant loops primed and coolant pump has been operated
- Continued to develop EVCU code and telemetry software
- Resolved a signal communications issue with Agility hydrogen storage system
- Continued full system test





Technical Progress – Fuel Cell Truck

Development of Fuel Cell Truck – Remaining task

- Fuel truck with hydrogen
- Continue commissioning of vehicle and subsystem
- Continue testing portion of testing and commissioning
- Continue work on electrical schematics
- Continue work on EVCU software and telematics

Technical Progress – CNG Hybrid Truck

Development of CNG Hybrid Truck

- Cummins Westport Inc. Near-Zero ISL-G Engine
- The CNG hybrid truck completed approximately 12 hours of local Rapid Mile Accumulation (RMA) testing
- Local runs are pulling a loaded trailer yielding a GVW: 66-68k lbs
- Expected to complete the reliability testing at Paccar Test Center and perform the final inspection, commissioning, and prepare the truck for delivery, Q2 2019

Complete integration of CNG Hybrid

Battery Disconnect Unit(BDU)

Parameter	Target	Measured
Range Total	150 miles	284 miles
Elec-Only	20 miles	26 miles
Top Speed	62 mph	65 mph

- Note: 80,000 lbs. GCW
- 1,000+ hours of operation and 1,793 of track and road miles

Lessons Learned

1. **Minimum traction power should exceed 320kW is required to handle speed at 6% slope.**

2. **80kW Fuel Cell is charge sustaining for Drayage/TTSI operation.**

3. **HMI has been redesigned from operator's experience**

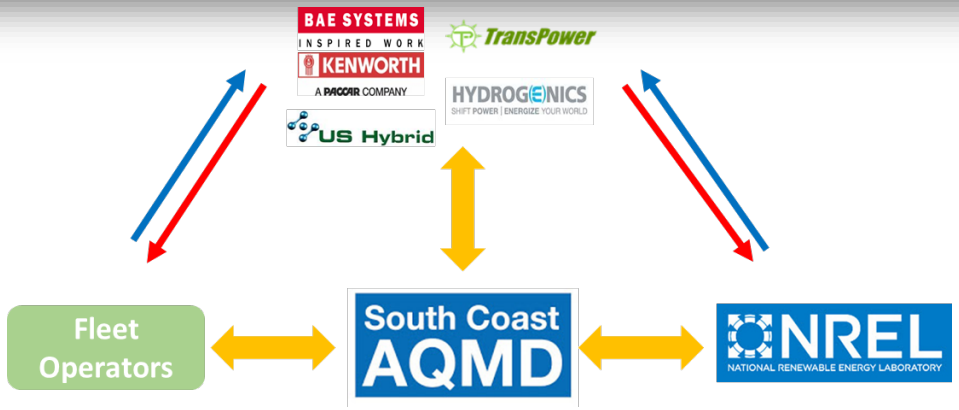
4. **Hydrogen storage tank is required to 35kg to operate over 250miles**

5. **Wire/pipe routing design has been improved for chassis layout**

6. **Battery management systems require self-diagnostics and auto-recovery**

7. **Cooling is critical for the system**

Future Research



1. **Collect real operation data from demonstration**
   - **Analyze the NREL provided data (GPS data, VMT, Efficiency, etc.)**
   - **Compare to conventional truck data with similar operating route**
2. **Analyze cost of ownership**
   - **Fuel cost**
   - **Maintenance cost**
3. **Establish a roadmap for commercialization roadmap**
   - **Market development strategy**
   - **Leverage the knowledge from this demonstration for other projects**

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Response to Reviewers' Comments

The reviewer assumed that the approach will shift to evaluating the zero-emission cargo transport (ZECT) vehicles' performance against comparable conventional vehicle performance in drayage operation. In the reviewer's opinion, these steps seem appropriate to achieve the project goals. The presenter stated that a formal total cost of ownership analysis is not part of this project, but that CALSTART is taking a look at that. The reviewer indicated that it would be nice to have that or a similar adoption analysis conducted as part of this specific project, to evaluate not only impacts from different levels of potential vehicle adoption, which is mentioned at the end of the presentation, but also what might be required to achieve the various penetration levels. (Reviewer 3)

Our project team is aware of what the customer requirements are as well as the duty cycles they put their vehicle through. Our technology partners are also addressing cost, weight, packaging challenges as well as efficiency, range and payload capacity by varying the size of the battery, fuel cell and hydrogen storage.
Once demo trucks are actively employed into regular service by fleet operators, a comprehensive data will be collected and compared with one collected from conventional vehicles with same duty cycles.
These tasks will enable to establish a roadmap for commercialization in the end of project.

The review commented coordination with the hydrogen supply side—permitting, etc.—remains a barrier. (Reviewer 5)
The reviewer noted that one of the identified barriers for the proposed technology is fueling infrastructure availability and location. (Reviewer 3)

Two new large capacity heavy-duty hydrogen fueling stations will be developed by Shell in Wilmington and Ontario, California and this project is funded by the Zero-Emission and Near Zero-Emission Freight Facilities (ZANZEFF) project by CARB. The new stations will join three additional stations located at Toyota facilities around Los Angeles to form an integrated, five-station heavy-duty hydrogen fueling network. Together, they will provide multiple sources of hydrogen throughout the region enabling zero-emissions freight transport.

Summary

- Temporary hydrogen refueling are supporting vehicle testing and demonstration
- TransPower and US Hybrid have deployed first fuel cell truck and being demonstrated at San Pedro Ports
- Second fuel cell trucks from TransPower and US Hybrid have been deployed
- BAE and Kenworth have deployed fuel cell truck and being demonstrated at San Pedro Ports
- Hydrogenics continues to make progress in build of fuel cell truck
- BAE and Kenworth completed build of CNG hybrid truck and tested ~2,000 of track and road miles
- Data collection and analysis followed by commercialization roadmap will be accomplished