Zero Emission Cargo Transport II

San Pedro Bay Ports Hybrid & Fuel Cell Electric Vehicle Project

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South Coast Air Quality Management District

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(This presentation does not contain any proprietary, confidential, or otherwise restricted information) [Project ID # VS158]




ZECT II 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
- BAE/GTI - CNG hybrid with catenary accessibility

Barriers & Challenges

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

Budget

- DoE: $10,000,000
- Funding partners: $7,183,979
- Contractors: $3,075,841

Total Cost:$20,259,820

ZECT II Goals

- Reduce criteria pollutants in South Coast Air Basin by reducing diesel emissions from transportation and movement of goods
- Accelerate introduction and penetration of zero and near-zero emission fuel cell and hybrid technologies in cargo transport sector




ZECT II Approach and Strategy

- Require contractors to have experience with fuel cell or battery electric truck and bus development
- Require contractors to partner with a major OEM
- Include funds for temporary infrastructure
- Leverage previous and ongoing project's vehicle technologies and infrastructure




BAE Electric Drayage Truck with Fuel Cell Range Extender

American Fuel Cell Bus Experience

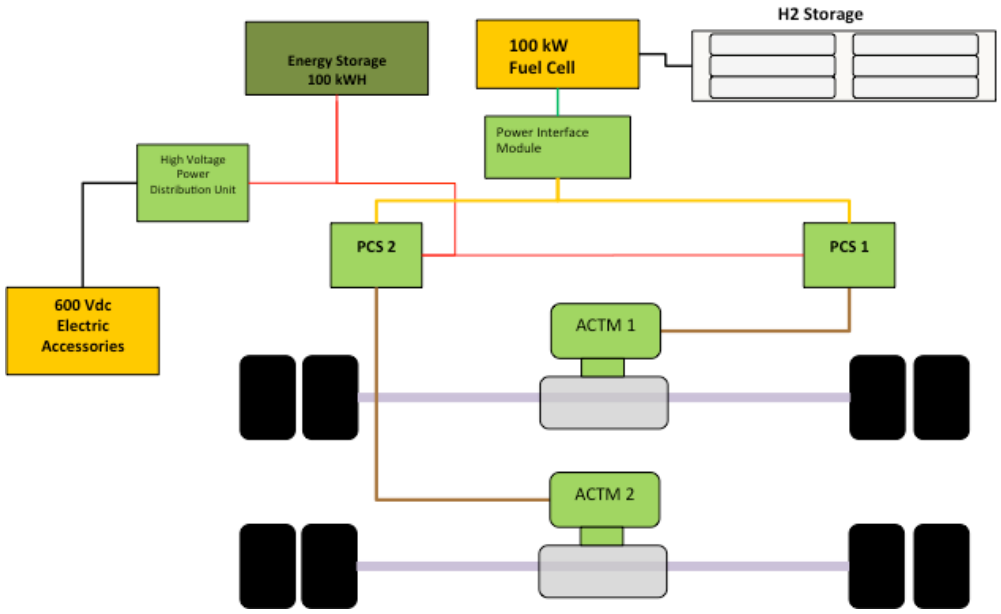
OEM Partner: Kenworth

BAE Electric Drayage Truck with Fuel Cell Range Extender Approach

- **Primary Power Source**
  - 100 kWh Lithium technology batteries
- **Auxiliary Power Unit (Range Extender)**
  - 100 kW Fuel Cell providing power to charge batteries
- **Electric Drivetrain**
  - Drivetrain will be based on BAE Systems HybriDrive® Series propulsion system
  - 2 dual propulsion control systems
  - 2 180 kW AC traction motors

Hydrogen Fuel

- 30 kg Onboard hydrogen fuel storage system



Technical Accomplishments and Progress: BAE Electric Drayage Truck with Fuel Cell Range Extender

- CTE contract was executed in May and was followed by a project kick off meeting
- CTE executed contracts with BAE and Kenworth
- Work has begun on the design and development phase of the project
- Kenworth is taking on World CNG's vehicle build activities and decided to use the T680 chassis
- Ballard will use their 7th Gen fuel cell for this project
- BAE is considering PHEV capability for the vehicle

TransPower Electric Drayage Truck with Fuel Cell Range Extender Approach:

- Current EV drayage truck and its use:
  - 80,000lb GCVW based on Navistar Prostar
  - 300kW peak motor power
  - 172 kWh usable battery energy (80%DOD)
  - 2.6kWh/mile demonstrated drive cycle demand
  - 7% bridge grades on standard route
  - EV range of 80-100 miles

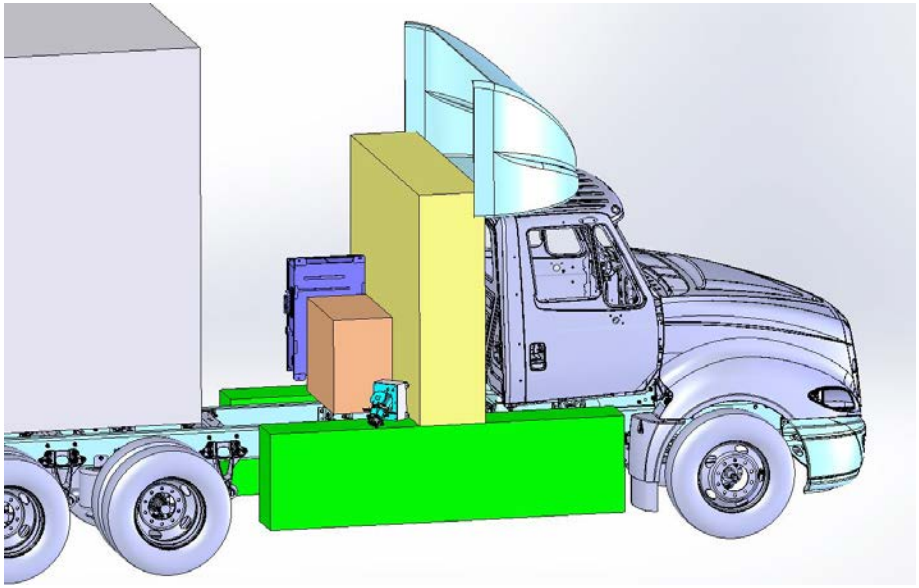
- Proposed truck with range-extending APU
  - Drop battery energy storage to 120kWh (80%DOD)
  - Add gaseous storage, FC Range Extender
  - Increase range to 135-200 miles

TransPower Electric Drayage Truck with Fuel Cell Range Extender Approach:

- Energy requirements:
  - for 150 miles, need 390kWh usable
  - 120kWh usable from 400Ah battery,
  - 17kg usable hydrogen, if used at 50% efficiency
- Power:
  - With full load, drawing as much as 220kW from battery (1.5C), 60kW from FCAPU, in warm weather continuous duty may be limited by motor heating

Technical Accomplishments and Progress: TransPower Electric Drayage Truck with Fuel Cell Range Extender

- Contracted executed in September, 2015
- Expected use is to extend reach of ZEV vehicles beyond the Long Beach area – to Ontario, Riverside, Orange county
- Serial hybrid combines TransPower's proven electric powertrain with a fuel cell APU
- TransPower's plan is to build and install FC APUs on two fully integrated truck systems, test and demonstration through drayage service
- APU fuel economy will be measured



Technical Accomplishments and Progress: TransPower Electric Drayage Truck with Fuel Cell Range Extender

- Simulated system efficiency to verify vehicle range using the HD FTP drive cycle
- Sized system fuel requirements, estimated ESS performance impacts of this design, and explored limited load following rules
- Operation at freeway speed possible for limited periods

Cycle/ Condition	Avg. Speed (MPH)	Trip Range (miles)	Operating Economy (kWh/mi)	Time to goal (hrs)	APU output (kW)	DC energy req'd (kWh)	Battery Capacity (kWh)	APU energy req'd (kWh)	H2 req'd (Kg)	
truck deliveries	33	135	2.7	4.1	60	365	120	245	16	
Drayage	10	75	2.7	7.50	15	203	120	83	5.5	
Drayage 2 shifts	10	150	2.7	15.00	20	405	120	285	19	

Technical Accomplishments and Progress: TransPower Electric Drayage Truck with Fuel Cell Range Extender

Long lead items on order

Component	Vendor:	Expected Delivery
Fuel Cells	Hydrogenics	Available – May - June
Inverters, DC-DC	EPC	May
Fuel Storage	A1 AutoElectric	August 2016

U.S. Hybrid Electric Drayage Truck with Fuel Cell Range Extender Approach

Development of 2 Fuel Cell Electric Plug-In Drayage Trucks using ZECT I Electric Truck Experience

- Fuel cell dominant
- US Hybrid 80kW power plant
- 320kW direct electric drive
- 26kWhr battery system
- Expected range 150-200 miles
- 20kg @ 350bar
- 6.6kW on-board charger

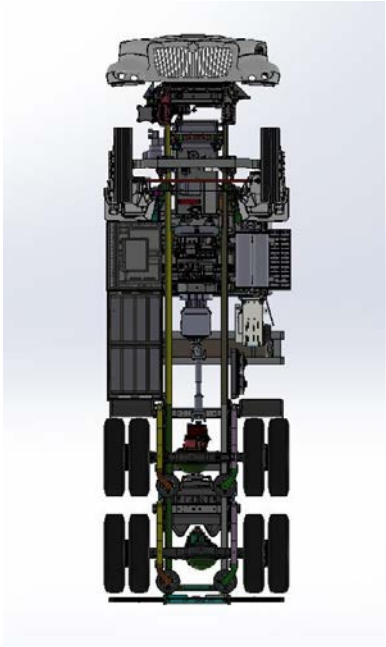
PureMotion™ 80
Fuel Cell APU

Vehicle OEM: International

Fleet Customer: TTSI

Technical Accomplishments and Progress:
U.S. Hybrid Electric Drayage Truck with Fuel Cell Range Extender

- Finalized the subsystem design and general vehicle layout
- Ordered two 80kW fuel cells to be delivered from the U.S. FuelCell facility in South Windsor, CT.
- Designed Hydrogen storage and fill system, identified suppliers, negotiated pricing and lead time



Technical Accomplishments and Progress:

U.S. Hybrid Electric Drayage Truck with Fuel Cell Range Extender

- Preliminary design of the battery housing and BMS system and has generated the preliminary drawings to be sent for fabrication quote and feedback
- Designed the vehicle electric driven auxiliary system and started the vehicle packaging of the auxiliaries

BAE CNG Hybrid Electric Drayage Truck

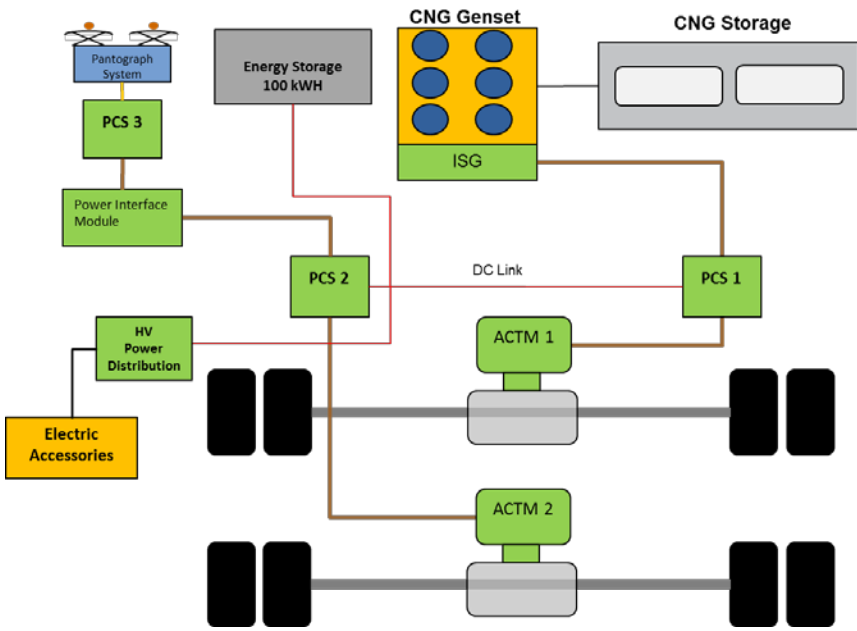
BAE: American Fuel Cell Bus Experience

OEM Truck Partner: Kenworth

BAE/Kenworth Drayage Truck with CNG Range Extender

Solution:

- Battery, catenary and a CNG genset to provide near-zero and zero emission heavy duty truck operation
- CNG genset used as an APU for range extension via battery charging
- A 50 – 100 kWh energy storage system
- The propulsion system based on BAE systems HDS300 with one SCU to control the system operation
- Two drive motors one on each rear axle to increase propulsion capability



Technical Accomplishments and Progress: BAE/Kenworth Drayage Truck with CNG Range Extender

- Sub Recipient contract with GTI is in place.
- Kenworth T-680 (Class 8) selected for vehicle platform
- Plug-in feature availability to charge battery system added
- Schedule updated:
  - Complete design and procure of log-lead items (Q4 2016)
  - Integrate and test the truck (Q2 2017)
  - Truck ready for service (Q3 2017)

International Rectifier

- In January 2015 Infineon acquired International Rectifier
- Infineon declined to continue IR's diesel hybrid truck development
- This leaves $825,784 in stranded funds in addition to cost share of $842,108
- Discussions have begun with the DOE project officer concerning these funds and will be resolved in 3rd Quarter

Response to Reviewers Comments

- (Q-3,R-2) The overview slide indicated $7 million contributed by funding partners as a separate item from the $3 million contractor cost-share but the reviewer did not catch who those funding partners include. The reviewer expressed the opinion that it would be good to have these partners called out as collaborators in the presentation. I agree and have added a Collaboration slide that includes funding partners.
- (Q-4,R-3) Future work to align specific architectures with specific duty cycles would be a great additional effort. NREL's DRIVE™ Tool will help us analyze the relationship between duty cycle, fuel economy, and emissions, as well as potential impact on life cycle costs, barriers to implementation, and public acceptance. This will enable us to align future work with architectures and duty cycles.
- (Q-6,R-1) The reviewer felt that requiring contractors to put up a larger percentage of the required funds would increase their incentive to get the technologies integrated into future product offerings and thus achieve a return on their internal investments. The large OEM's we want to engage currently do not include these technologies in their product plans so requiring higher cost-share would further discourage their participation.

Collaboration

- **Financial Partners:** California Energy Commission $2.4M, Ports of Los Angeles & Long Beach $1.1M, Los Angeles Department of Water and Power $1M, Southern California Gas $250K
- **OEM's and Vehicle Integrators:** BAE, Kenworth, International, TransPower & U.S. Hybrid
- **Project Implementation Partners:** GTI & CTE
- **Data Collection & Analysis:** NREL

ZECT II Status & Future Activities

- Contracts with TransPower, U.S. Hybrid, CTE and GTI have been executed
- International Rectifier (IR) and their diesel hybrid truck are no longer part of the project
  - Unused IR funds will be reallocated
- Technical teams are proceeding on project tasks
- Vehicle design, analysis, equipment purchase and integration work is in process for all project participants
- All projects will conduct 24 month on-road demonstration and data collection after vehicles are completed