

# Zero Emission Heavy Duty Drayage Trucks Demonstration



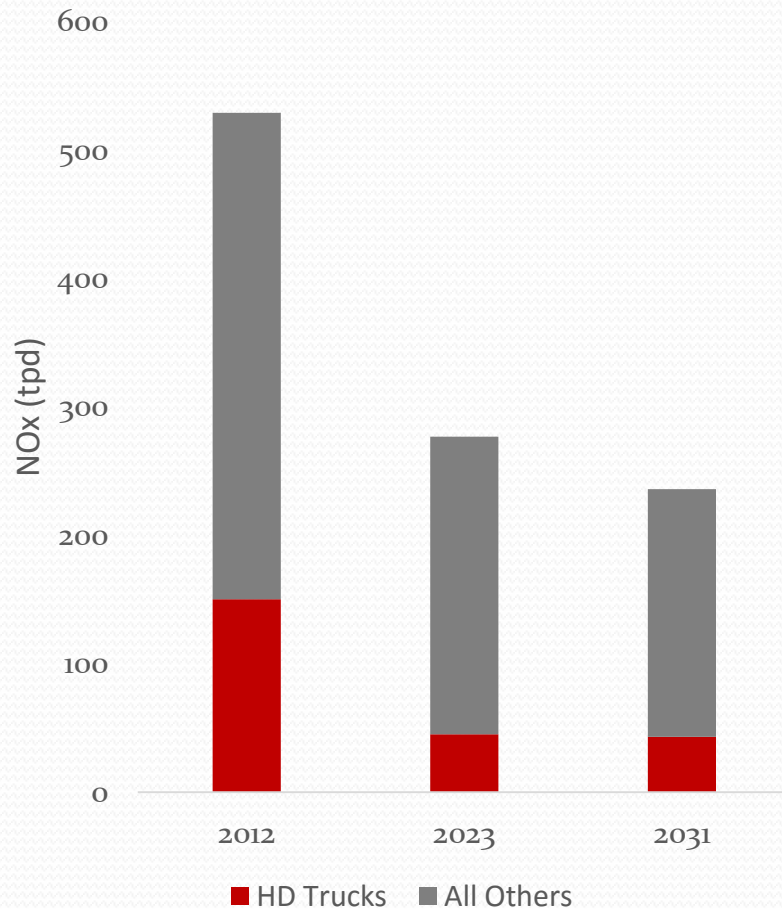
Brian Choe  
Clean Fuels Advisory Group  
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# Agenda

- Zero Emission Heavy Duty Drayage Trucks Demonstration Overview
- Technology Review and Progress Update
  - Battery Electric & Hybrid Electric
  - Fuel Cell and Catenary (Joe Impullitti)



# Background



- Heavy-duty (HD) trucks remain one of the largest source of NOx emissions in the South Coast Air Basin
- Disproportionate impact on communities near the San Pedro Bay Port and along goods movement corridors
- High priority to develop zero and near-zero emission HD truck technologies

# Demonstration Approach/Objectives

- Develop HD truck technologies with zero emission operation capability
  - Leverage state and federal funding programs
  - Collaborate with regional and industry stakeholders
  - Engage large truck OEMs
  - Leverage previous and on-going projects
- Demonstration in real world drayage operation with fleet partners
  - Assess technical and commercial viability
  - Promote market acceptance
- Collect and analyze performance and O&M data



# Demonstration Portfolio

Architecture	Manufacturer	ZECT I	eHwy	ZECT II	GGRF	Total
BEV	BYD				25	25
	TransPower/Peterbilt	4	1*		12	17
	US Hybrid	2				2
PHEV	BAE/Kenworth			1*	4	5
	TransPower	2	1*			3
	US Hybrid	3				3
	Volvo		1*		2	3
FCEV	BAE/Kenworth			1		1
	TransPower			2		2
	US Hybrid			2		2
	Hydrogenics/Daimler			1**		1
<b>Total</b>		<b>11</b>	<b>3</b>	<b>7</b>	<b>43</b>	<b>64</b>

\*Catenary

\*\*Pending Board approval

# Technology Review and Progress Update

## Battery Electric Trucks (BETs)



# BET Technology

- Electric vehicles powered by rechargeable batteries on-board
- Simple and efficient system
- Zero tailpipe emissions
- Smooth and quiet operation
- Low fuel and maintenance costs



# BET Technology Challenges and Barriers

- Limited range & payloads
- Long recharging time
- Inadequate charging infrastructure
- Charging standards yet to be established
- High capital cost, both in development and incremental cost
- Unproven technology – Fear of unknown



# BET Technologies

	BYD	TransPower/ Peterbilt	US Hybrid
Chassis	BYD T9	International Prostar/ Peterbilt 579	International Prostar
Traction Motor	Two In-Line Motors 180 kW each	Dual Motor Unit 300 kW	Induction Motor 320 kW
Transmission	Automated Manual	Automated Manual	Direct Drive
Battery (kWh)	207	215/311*	240
Charger	On-board 80 kW	On-board ICU 70 kW/200 kW*	On-board 60 kW
Recharge Time (hr)	2-3	3-4/1-2*	4
Range (mile)	70-100	80-100/120-150*	70-100

\*Applicable only to 4 of 12 Peterbilt trucks to be developed under the GGRF project

# Progress Update

## ZECT I BETs – TransPower

- Completed all four Electric Drayage Demonstration (EDD) trucks
- EDD2 tested on chassis dynamometer at UCR in Q4 2014
  - DTP and UDDS Cycles (72,000 lbs)
  - 2.06 - 2.42 kWh/mile
  - 7% grade simulation
- EDD2, EDD3 and EDD4 currently in drayage service
  - Mostly local operations with over 13,000 drayage miles accumulated
  - Quiet and smooth operations with comparable power and torque
  - Improvement needed on range and payload limitation



EDDs



EDD2 on Chassis Dyno at UCR

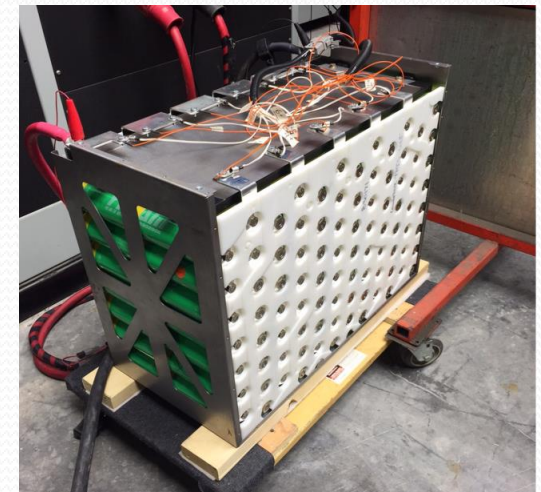
# Progress Update

## ZECT I BETs – TransPower (Continued)

- Limited operations for EDD1 with older generation cells and BMS due to unreliable cells and BMS
- To be upgraded with new battery cells and BMS by Q3 2016
  - KAM cells with 60% higher energy density
  - 311 kWh in similar system weight & volume as for 215 kWh battery pack
  - 120-150 miles in operating range
  - Advanced BMS to provide dynamic balancing capability



EDD1



KAM Battery Module

# ZECT I BETs

## Data Collection & Analysis

### TransPower BETs

- 1/15 through 6/30
- EDD2 - EDD4
- 297 days of operation
- 13,150 miles traveled
- Local operations

### Baseline Trucks

- 10/14 through 2/15
- Two diesel trucks (2013 Mack)
- 166 days of operation
- 23,590 miles traveled
- Filtered for local operations



# Average Daily Use

	EDDs	Baseline Diesel
Operation Time	4.5 hrs	7.4 hrs
Idle Time	2.2 hrs	3.4 hrs
Distance	44.2 miles	86.4 miles
Trailer Distance	28.1 miles	N/A
Average Total Speed	12.0 mph	12.0 mph
Average Driving Speed	20.0 mph	21.8 mph
Fuel Consumption	2.2 kWh/mi (18.0 MPGde)	6.6 kWh/mi (5.8 mpg)
Regen Energy	0.37 kWh/mi	N/A
Ending SOC	54.8%	N/A
Kinetic Intensity	1.19	0.77



# Progress Update

## ZECT I BETs - US Hybrid

- Completed first BET in Q3 2015
  - Developed and integrated on-board charger
  - Modified drive train to direct drive (cost & weight benefits)
- Chassis dyno testing at UCR in Q4 2015
  - DTP and UDDS Cycles with 70,000 lbs. GCWR
  - Preliminary results show 2.2 to 2.8 kWh/mi (DTP) & 3.0 kWh/mi (UDDS)
- On-road testing including Vincent Thomas Bridge (7% grade) with a fully loaded container
- Deployed in drayage service in early Q3 2016



US Hybrid BET on UCR Dynamometer



US Hybrid BET During On-Road Testing



# Progress Update

## GGRF BETs

- Agreement with CARB to be completed within next 30 days
- Contracts with OEMs to be executed in Q4 2016
- BYD to develop 25 BETs based on T9 Prototype
  - Phase 1 trucks (5) – Q1/Q2 2017
  - Phase 2 trucks (20) – Q1/Q2 2018
- TransPower/Peterbilt to develop 12 BETs based on EDD drivetrain
  - Phase 1 trucks (4) – Q3 2017
  - Phase 2 trucks (8) – Q3 2018
- Project to be completed by April 2019



BYD T9



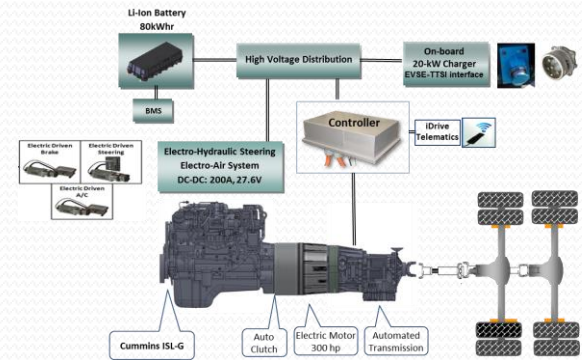
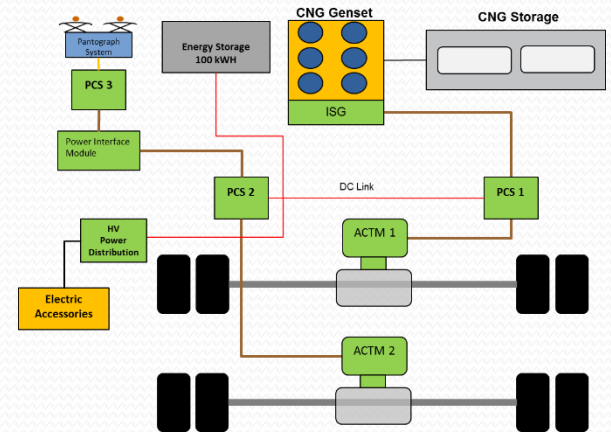
EDD Truck

# Technology Review and Progress Update

## Plug-In Hybrid Electric Trucks (PHETs)

# PHET Technology

- Electric drive with auxiliary power unit (APU) for extended range and augmented power
  - Series hybrid
  - Parallel hybrid
- Support a wider range of duty cycles
- Zero emission operation capable in sensitive zones
- Steady state operation to minimize fuel consumption and emissions
- Refueling time comparable to conventional trucks



LNG Plug-In Hybrid Electric Drayage Truck "PHET" Powertrain System Configuration

# PHET Technology

## Challenges and Barriers

- Optimized balance of power and capacity between traction motors and APU
- High incremental cost
- Hybrid system weight penalty
- Certification standards yet to be established



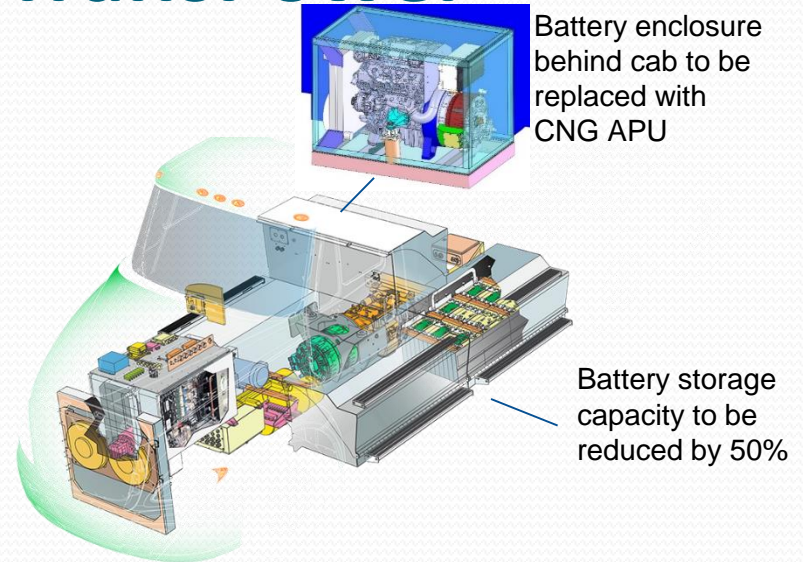
# PHET Technologies

	<b>BAE/Kenworth</b>	<b>TransPower</b>	<b>US Hybrid</b>	<b>Volvo</b>
Chassis	Kenworth T680 & Peterbilt 579	International Prostar	Peterbilt 384	Mack Pinnacle
Traction Motor	Two 200 kW Motors (one on each real axle)	Dual Motor Unit 300 kW	PM Motor 223 kW	PM Motor 150 kW
Transmission	Automated Manual	Automated Manual	Automatic	Automated Manual
APU	Cummins 8.9L CNG	Ford 3.7L CNG	Cummins 8.9L LNG	11L Diesel
Battery (kWh)	50-100	155	80	10-20
Storage Tank (DGE)	40-50	60	72	75
Charger	Off-board 90 kW	On-board ICU 70 kW	On-board 20 kW	On-board 11 kW
Recharge/Refuel Time	1-2 hrs/ 10-15 min	2-3 hrs/ 10-15 min	4 hrs/ 10-15 min	1 hr/ 10-15 min
AER/Range (mile)	30-40/150-200	30-40/150-200	30/250+	10/300+

# Progress Update

## ZECT I PHETs - TransPower

- Project added to ZECT I in Q3 2015
- Series hybrid system based on the ElecTruck™ system with a 3.7L CNG engine APU
- A prototype generator on the eHighway catenary truck undergoing testing and fine tuning
- Development of engine test dyno for calibration and validation
- Long lead components ordered
- First PHET to be completed by Q4 2016



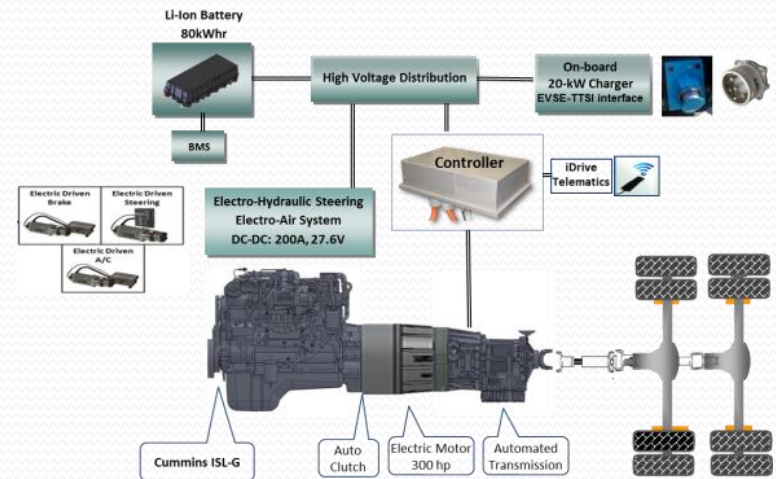
TransPower CNG Catenary Truck



# Progress Update

## ZECT I PHETs - US Hybrid

- Project added to ZECT I in Q3 2015
- Parallel hybrid system to convert three LNG trucks with 8.9L ISLG LNG engine
- Capable of providing higher power and torque than ISX 12 & ISX 15
- First PHET completed in time for 2016 ACT Expo in May
- Currently undergoing on-road testing for fine tuning and validation
- Chassis dyno testing at UCR in Q3/Q4 2016
- Deployment with TTSI in Q4 2016



LNG Plug-In Hybrid Electric Drayage Truck "PHET" Powertrain System Configuration



# Progress Update

## GGRF PHETs

- Contracts with OEMs to be completed in Q4 2016
- Volvo to demonstrate two PHETs developed from prior projects, focusing on efficiency and emission optimization
  - Phase 1 deployment in Q4 2017
  - Phase 2 deployment in Q4 2018
- BAE/Kenworth to build four PHETs based on ZECT II PHEV system
  - Phase 1 deployment in Q1 2018
  - Phase 2 deployment in Q1 2019



Volvo PHET Prototype



Kenworth T680

# Questions & Discussion