31ST WORLD LPG FORUM
2-4 OCTOBER 2018
HOUSTON

GTC

WLPGA GLOBAL TECHNOLOGY CONFERENCE

An LPG Near Zero Emission System for Forklifts

Tecogen

LPG
EXCEPTIONAL ENERGY

Forklift Application – Market &Regulatory Drivers

- LPG forklifts facing serious challenges from electric counterparts
  - Improvements in battery technology
  - Increasing pressure to phase out fossil fuels (CARB, Europe)
- Regulatory Drivers
  - End user compliance based on fleet averages (CARB)
  - OEM Compliance
    - Engines certified to the optional emission standards can help customers achieve their fleet average
    - CARB offers generous incentives for near-zero onroad trucks - outreach is needed for offroad (i.e. forklifts)

End User Compliance Requirements (NOx +HC)

Fleet Type	Number of units	Fleet Average Emission Level g/kw-hr (g/bhp-hr)		
		1/1/2009	1/1/2011	1/1/2013
Large forklift fleet	26+	3.2 (2.4)	2.3 (1.7)	1.5 (1.1)
Mid-size forklift fleet	4-25	3.5 (2.6)	2.7 (2.0)	1.9 (1.4)
Non-forklift fleet	4+	4.0 (3.0)	3.6 (2.7)	3.4 (2.5)

OEM Compliance Requirements

Model Year	NOx + HC [gm/kW-hr]	CO [gm/kW-hr]
< 2000	16	
2001 -2006	4.0	49.6
2007 - 2009	2.7	4.4
≥ 2010	0.8	20.6
≥ 2010 (optional)	0.5, 0.3, 0.1	20.6

LSI Emission Standard > 1.0L Engine

Ultera® Solution for Near Zero NOx Operation

- Tecogen Ultera is a tool for LPG forklifts to achieve the lower emission standards
- PERC (Propane Education and Research Council) funded demonstration program
  - Industry support from MCFA (Mitsubishi Caterpillar Forklift America)
    - Contributed forklift – Cat Lift Truck Model GP25N (2.5L engine)
- Add-on aftertreatment system
  - Scales to all engine sizes
  - Can be a retrofit kit
- Ultera also benefits indoor air quality with low CO exposure
  - Food distribution compatible
  - Enhances clean & green corporate image

Ultera
EMISSION CONTROL

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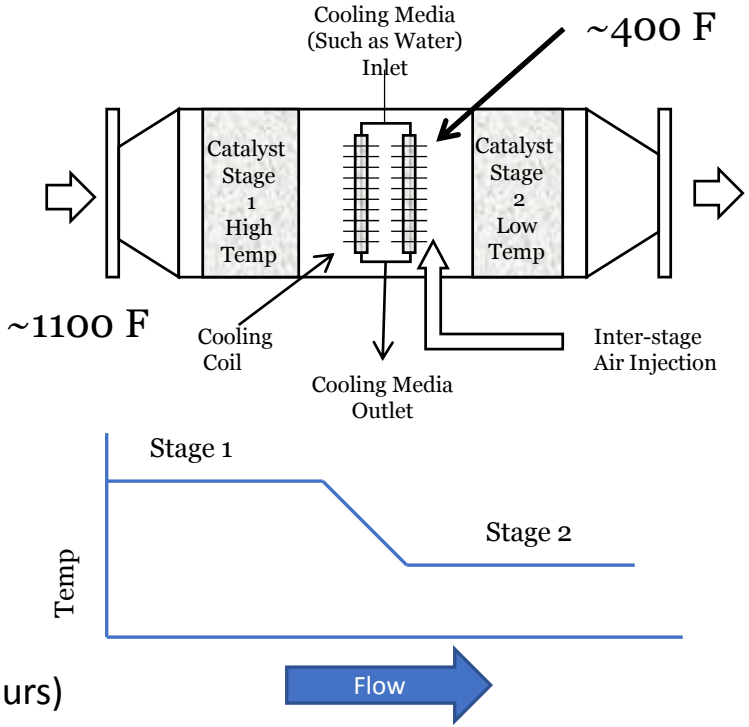
Tecogen Ultera Technology

- Stationary NG engine scrutinized
  - Unannounced testing by regulators (SCAQMD)
  - Exposed widespread non-compliance
  - Regulators lowered compliance levels and established ongoing compliance protocol
- Achieved groundbreaking patented process: Ultera®
  - Stage 1: Operate to Minimize NOx (Rich)
  - Stage 2: Inject Air Upstream to Create Oxidizing Environment
  - But NOx reformed in second stage
  - Patented Breakthrough: Interstage Cooling
  - Highly Tolerant of Air/Fuel Deviations
- Widely deployed by Tecogen in products throughout USA including California (Hundreds of engines, thousands of hours)

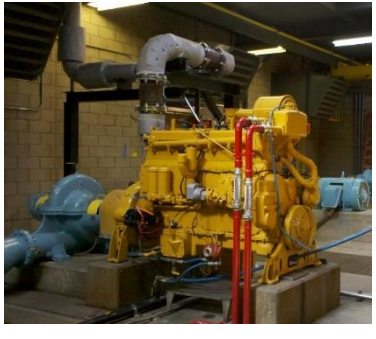


Independent Testing on Various NG Engine Platforms

	Tecogen Ultera Aftertreatment			Fuel Cell
	General Motors Nat Gas Engine 8000 Hour Source Test	Ford Nat Gas Engine AVL Testing	Caterpillar Nat Gas Engine California Municipal Water Pump Station	California Energy Commission Field Tests 18 Units
NO_x	0.6	0.9	0.2	0.5
CO	1.5	0.3	4	1.1
NMHC	not measured	0.1	not measured	not measured
VOC's	2.5	not measured	not measured	not measured

Note 1: All values are measured concentrations in parts per million (PPM) corrected to an air dilution of 15%, which is the standard unit of measure in California air quality testing and permitting.

Note 2: VOC's (volatile organic compounds) and NMHC (non-methane hydrocarbons) are both measurements of organic gases which are harmful pollutants.



- Performance exceeds SoCal regs by wide margin
  - Comparable to natural gas fuel cells
- Demonstrates ease of technology transfer
  - Large and small engines
  - Indifferent to manufacturer
- Solves the problem associated with the inherent limits of three-way catalysts
  - Extremely large excursions with small adjustment in engine operating parameters
- Repeatable chemistry with carbon-based fuels (NG, LPG, Gasoline)

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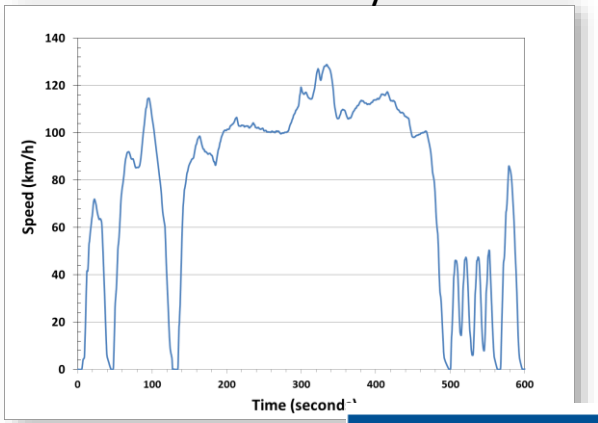
Tested on Mobile Application - Gasoline PC

US06 Drive Cycle



- 87% CO reduction
- 86% NMOG reduction
- 20% NOx reduction
- 26% NOx + NMOG reduction

	CO	NMOG	NOx	NMOG + NOx
		Pre – Ultera® System		
Grams	9.56	0.042	0.445	0.487
grams/mile	1.18	0.005	0.055	0.060
		Post – Ultera® System		
Grams	1.25	0.006	0.356	0.362
grams/mile	0.155	0.001	0.044	0.045
Reduction Efficiency	87%	86%	20%	26%
Total Grams Removed	8.31	0.036	0.088	0.124

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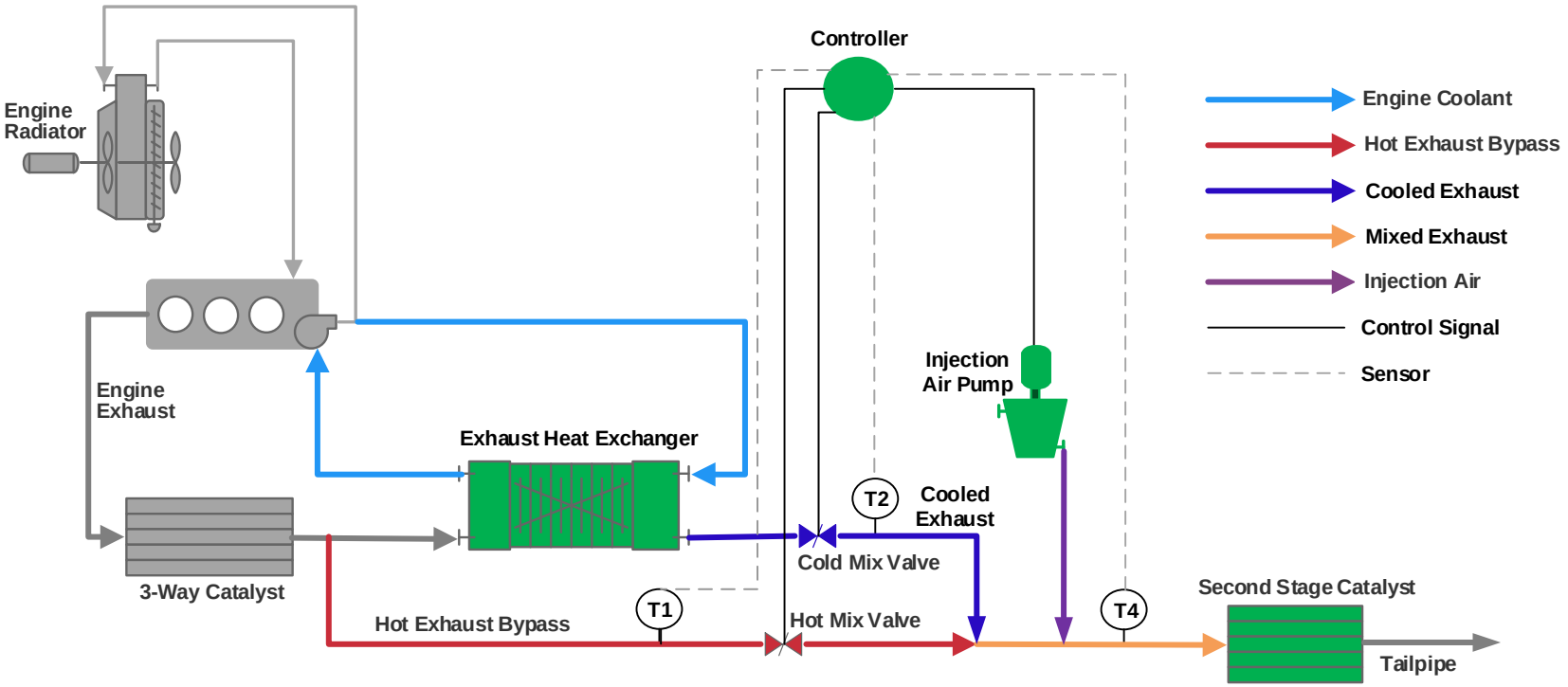
Process and Instrumentation Diagram



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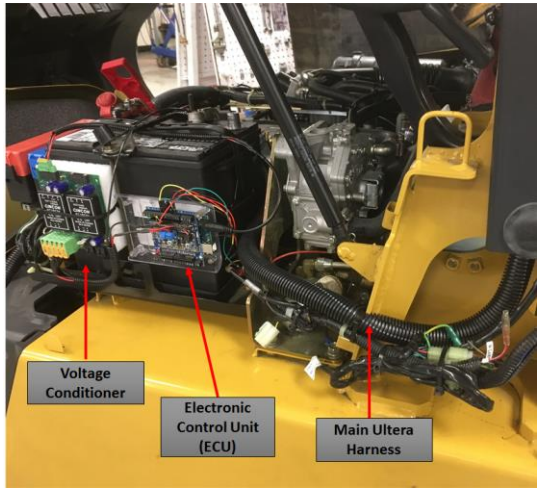
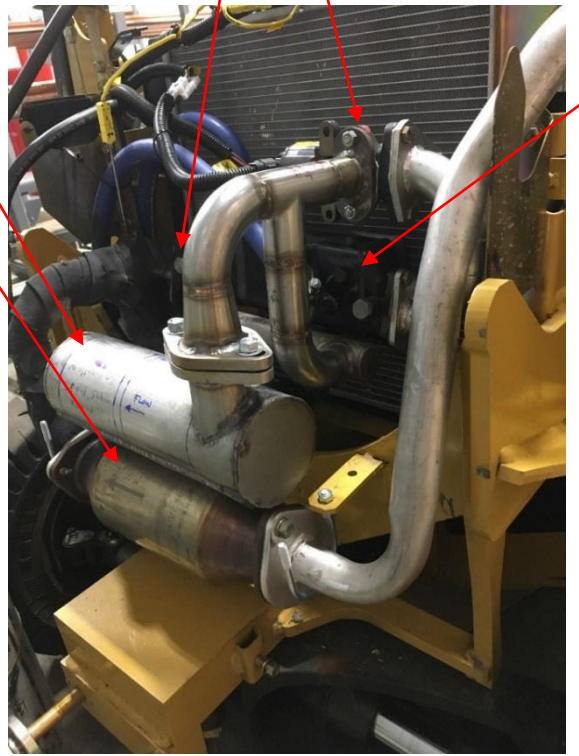
Ultera Forklift Integration

- Stock exhaust system
  - 3-way catalyst, muffler, radiator
- Fully integrated under counterweight
- Factory AFR
  - Project scope did not allow for adjustments/retuning



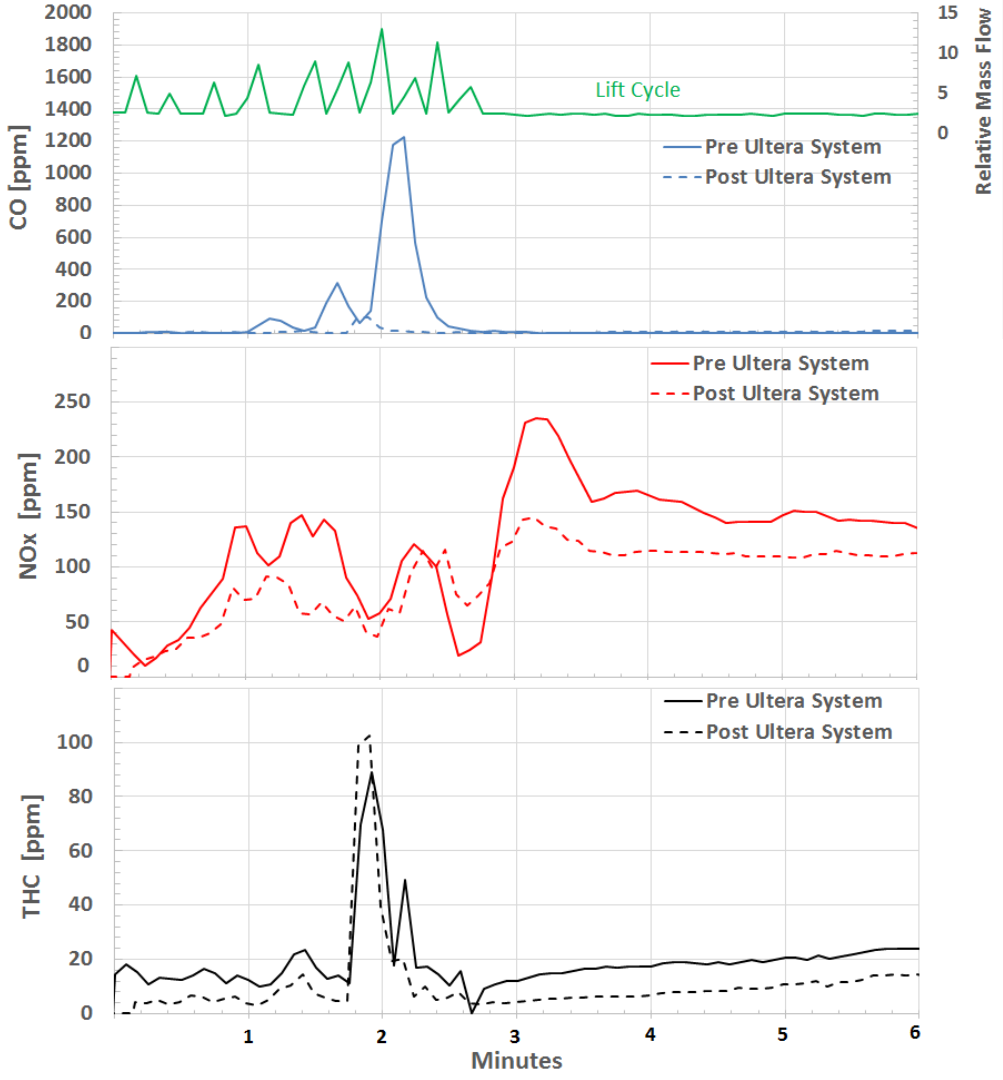


Ultera Performance

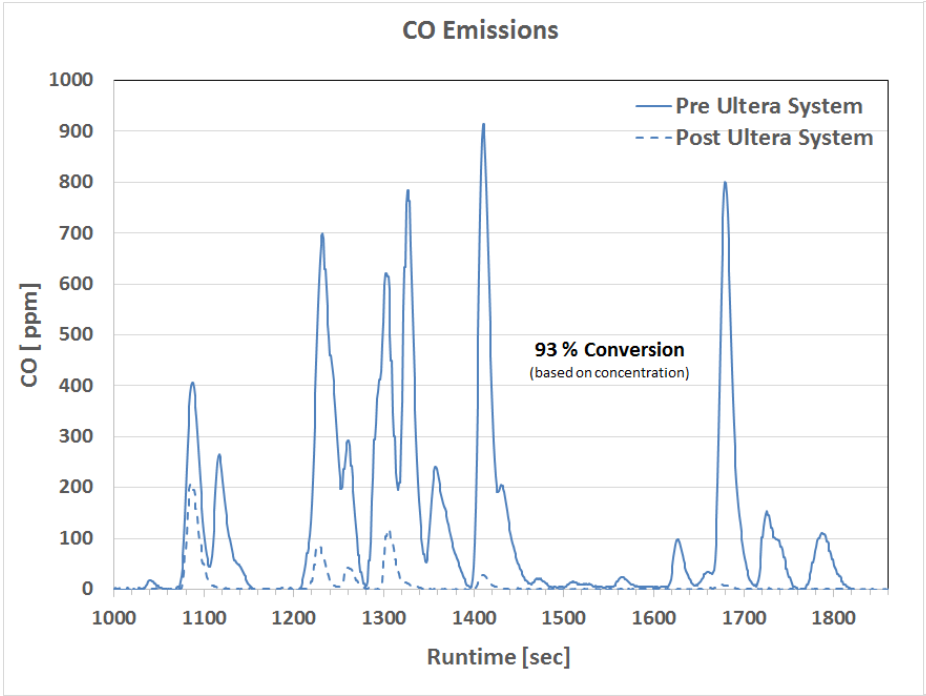
- 4300 lb lift cycle
  - OEM factory AFR calibration
- Third-party validation
  - Confirmed CO and NOx trends
  - THC data
- % Reduction based on pollutant mass

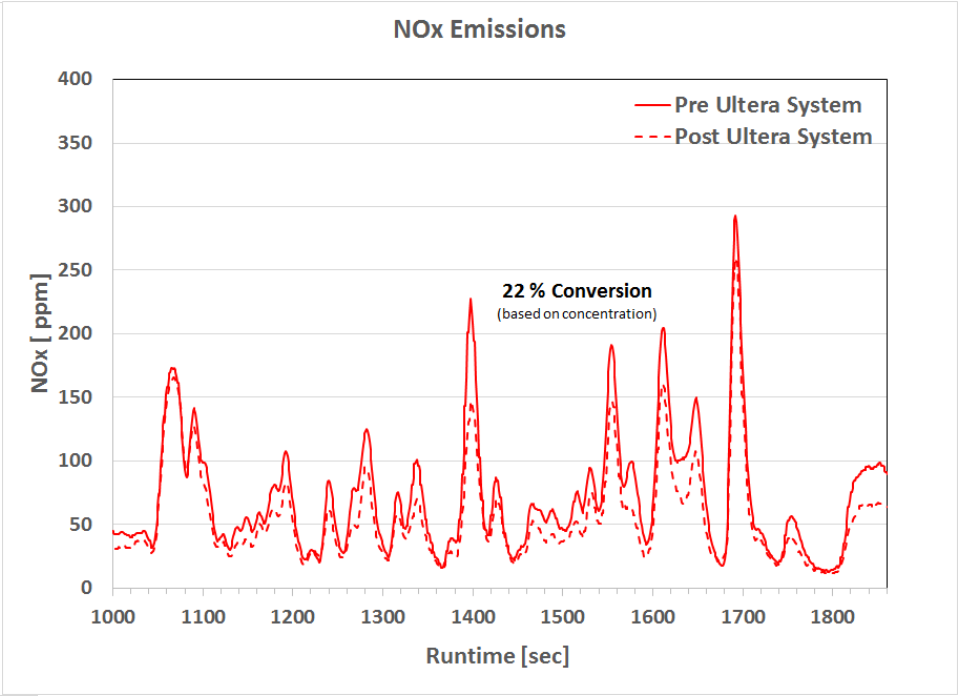
	Tecogen	Third-Party
CO	98.8%	91.0 %
THC	N/A	52.1%
NOx	24.3%	29.2%

* *Based on estimated mass flow*



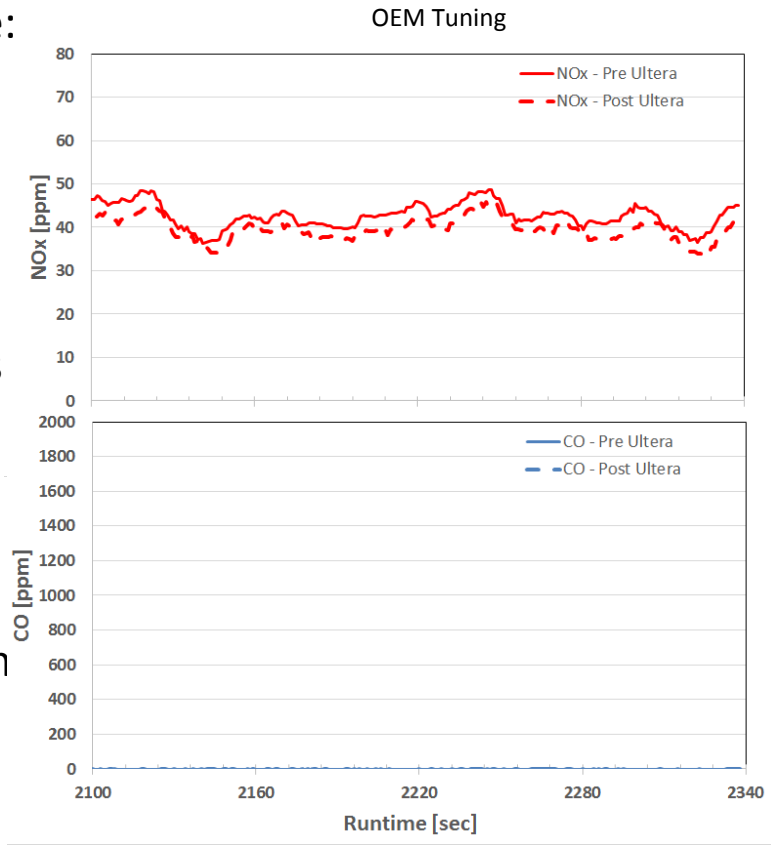
Driving/Lift Test

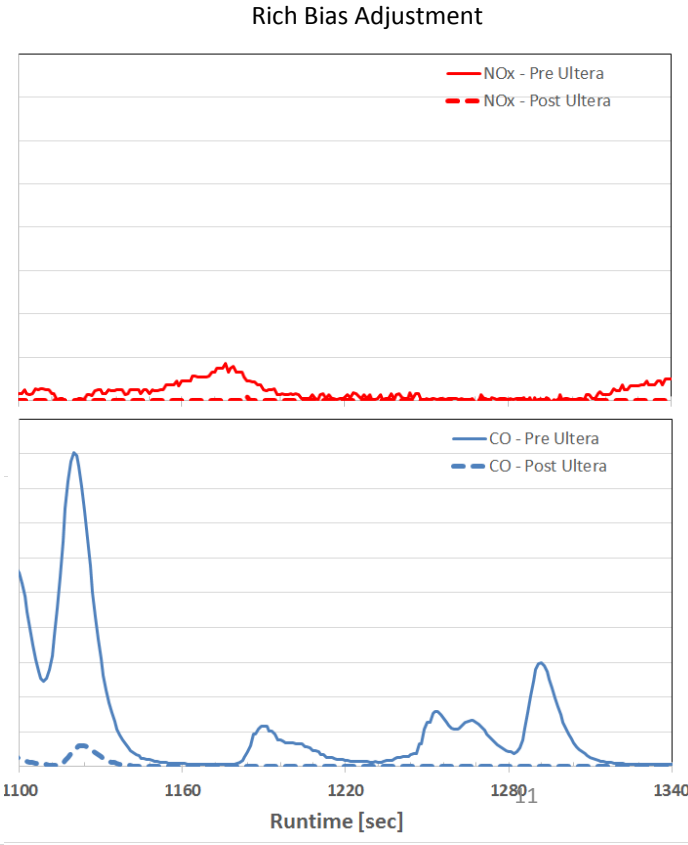




Near Zero NOx Achievable with Control Tuning

- At Normal Idle Mode:
  - Engine runs lean (1.025)
  - Higher NOx / near-zero CO results.
- AFR Rich Shift Allows
  - Near-zero NOx
  - Ultera removes CO
- Final development phase underway with AFR optimization





Conclusion/Next Steps

- Ultera Technology can preserve market share for LPG forklifts
  - Near-zero NOx engine provides an alternative to electric for lowering fleet averages
  - Improve outdoor air quality – particularly in non-attainment, highly commercial regions
    - Freight distribution centers, ports
  - Improve indoor air quality with low CO exposure
    - Food distribution compatible
    - Enhances clean & green corporate image
- Next Steps
  - Complete development work with AFR tuning
  - Validate on OEM test track
  - Partner with OEM(s) for CARB certification
  - Outreach to CARB for end-user incentive
  - Develop retrofit kits for a range of engine sizes

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