Achieving High-Efficiency Clean Combustion in Diesel Engines

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Project Overview

Research potential of new combustion regimes that exhibit simultaneous low engine-out NO_X and PM emissions while maintaining efficiency *only using production-like controls*.

Motivation

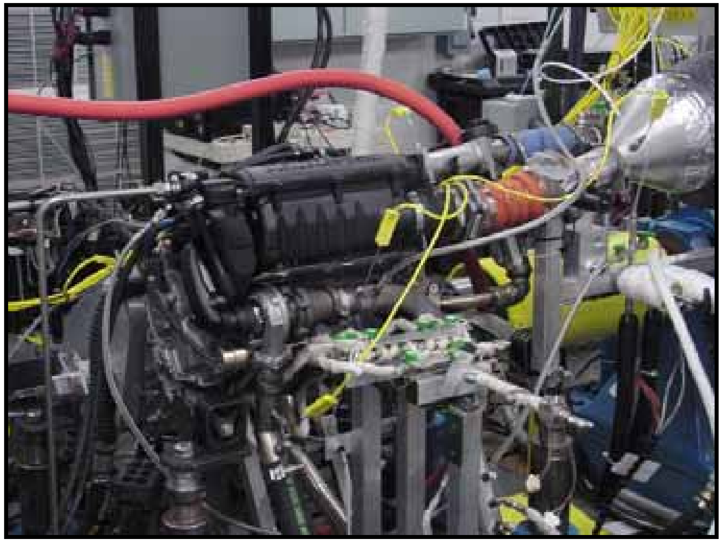
Improving system *efficiency* by lowering performance requirements for post-combustion emissions controls.

Near-Term Objectives

- Investigate transition between normal and advanced combustion operation.
- Maintain efficiency during LTC operation.
- Investigate effects of fuel properties on achieving LTC operation.
- Perform thermodynamic analysis on non-traditional combustion modes.

Experimental Platform

- Mercedes 1.7-L engine
- SwRI RPECS-based controls (currently being updated to dSpace/VEMPS based system).
- Instrumentation for gaseous emissions and particulate matter.
- All four cylinders instrumented with pressure transducers.
- Minimal hardware modifications.



Number of Cylinders	4
Injection System	Bosch Com Rail
Bore, mm	80.0
Stroke, mm	84.0
Compression Ratio	19.0
Piston Geometry	Re-entrant bowl
Rated Power, kW	66
Rated Torque, Nm	180

Injection parameters and EGR were used to explore low emission regimes

- Majority of experiments performed under conditions with no intake charging.
- Majority of results shown for “road load” condition.

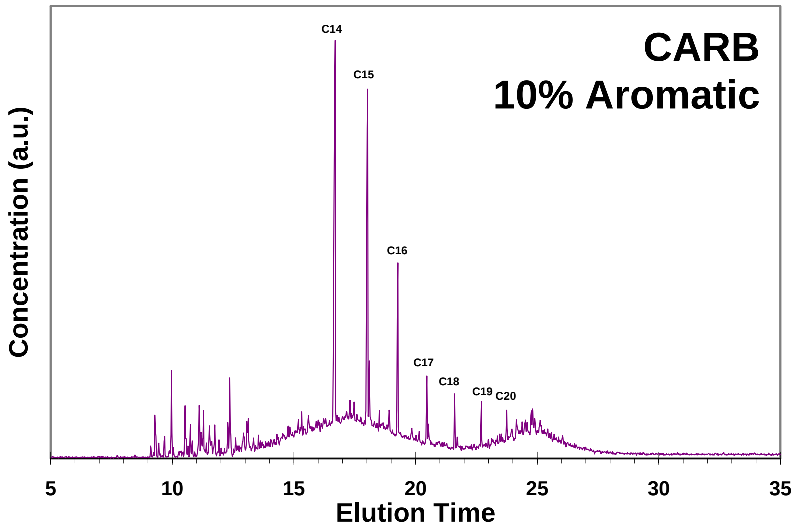
Base Condition
experiments shown

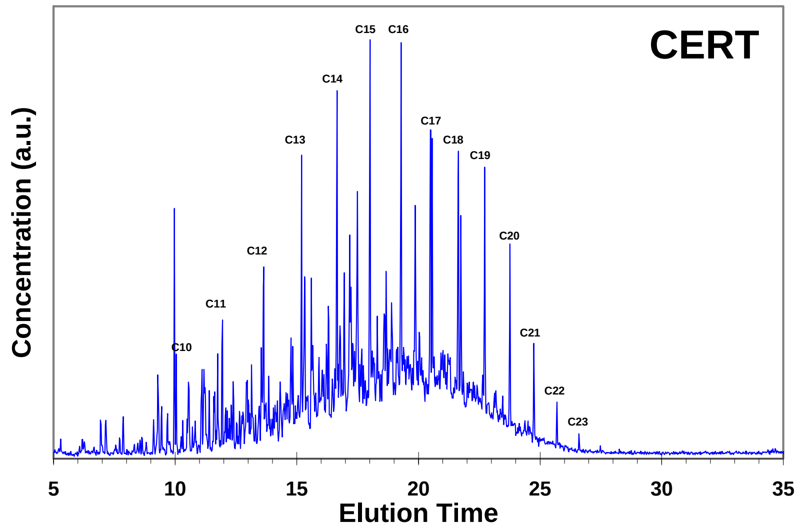
Torque, Nm	34
Speed, rpm	1500
Rail Pressure, bar	320
Main PW, ms	0.554

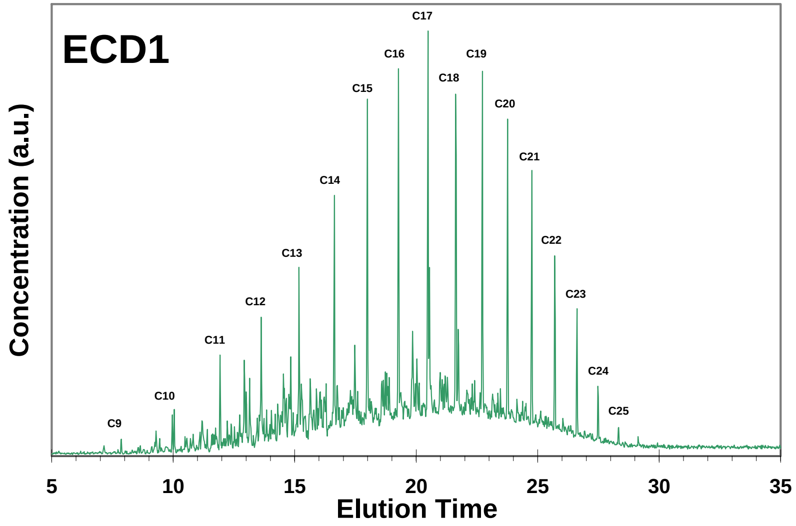
Pilot PW, ms	0.284
Main Timing, ^{o} BTDC	2
Pilot Gap, ms	1.8
EGR Rate, %	22

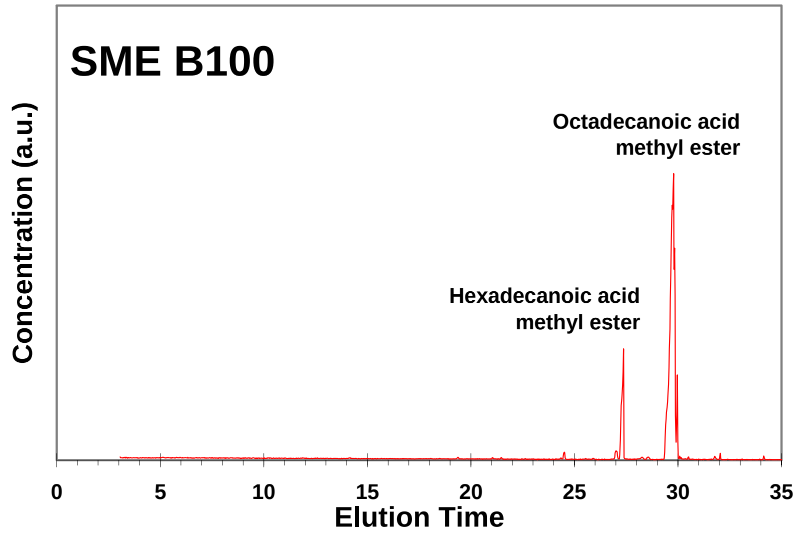
Effect of Fuel Properties on Achieving Low-NOx Low-PM Operation

Investigated ability to achieve low-NOx low-PM operation with four fuels







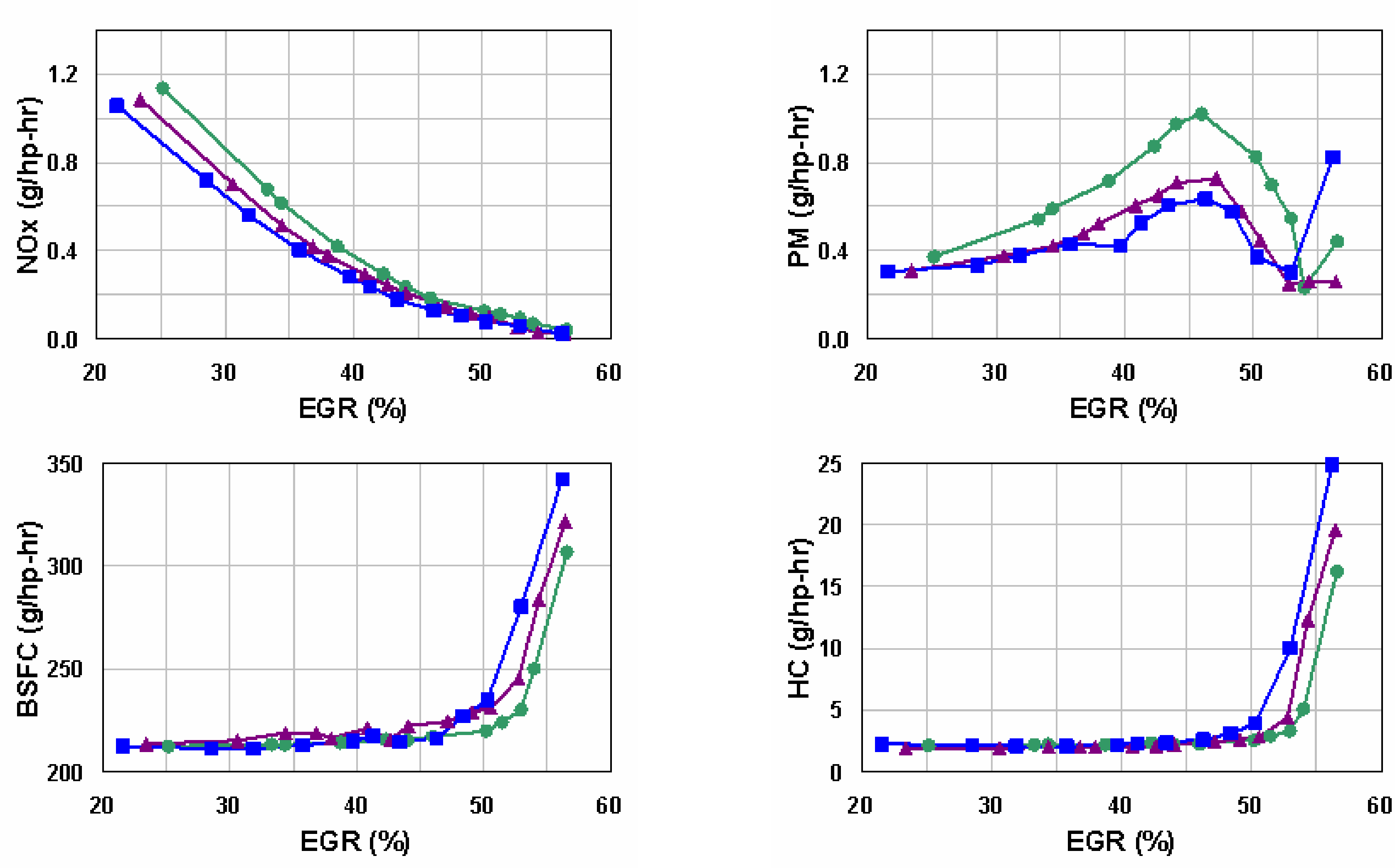


Important experiment information to note ...

- Cetane number varies from 47.3 for Certification fuel to 54.2 for ECD1 fuel.
- Injection parameters were not optimized for each fuel.
- Torque at base condition set to 25.9 ft-lb for each fuel.
- Purpose of these preliminary experiments is to see if each fuel is capable of low-NOx low-PM operation.

Achieved low-NOx low-PM operation for three fuels

(CARB ▲ / CERT ■ / ECD1 ● / SME-Not Shown)



Transitioning to and Achieving Efficient Low-NOx Low-PM Operation

Transitioning between *conventional* and *advanced* operation

- Ability to recover efficiency during LTC operation strong function of transition rate.
- Slow transition (e.g., hours during detailed sweep) results in higher PM as compared to fast transition (e.g., seconds).
- Only basic injection parameters used to recover efficiency.
- PM spike during transition is probably not significant (conflicting results due to engine problems).
- Transition to *efficient LTC operation* difficult on this engine under boost conditions.

Important experiment information to note ...

- Inducted EGR/air mixture temperature is not controlled.
- All experimental results shown are for lean operation.
- Only hardware modifications include EGR cooler (engine coolant) and intake throttle.
- Experiments performed from perspective of only production-like hardware available.

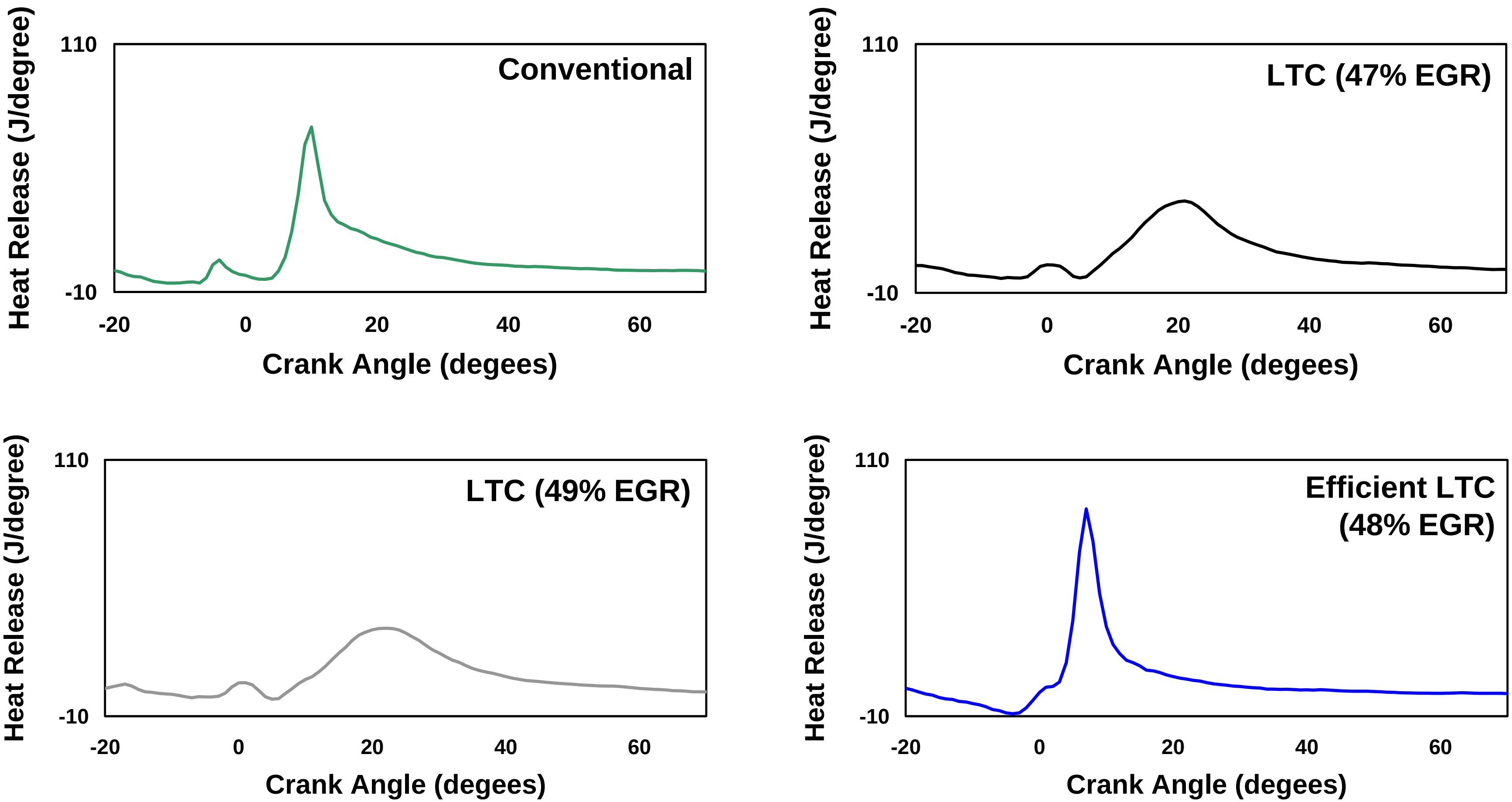
Efficiency maintained with low-NOx and low-PM

(1500 rpm, 2.6 bar BMEP)

	Base	LTC	Efficient LTC
EGR (%)	21	49	48
BSFC (g/hp.hr)	211	240	209
NOx (g/hp.hr)	1.2	0.1	0.1
PM (g/hp.hr)	0.38	0.51	0.29
THC (g/hp.hr)	2.68	4.54	2.46
Intake Temp (C)	43	129	94
Exh Temp (C)	205	244	199
Main Timing (BTDC)	2	2	12
Pilot Timing (BTDC)	18	18	none
Rail Pressure (bar)	320	320	328

Transition to LTC occurred in several seconds (not hours).

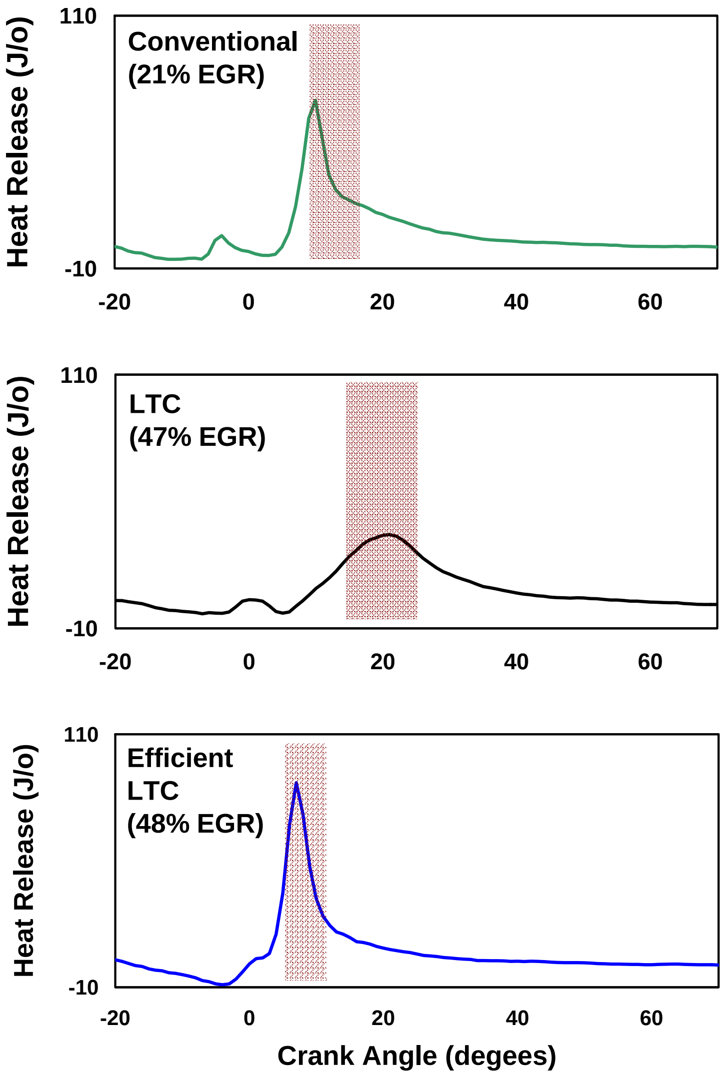
Significant shift observed in heat release profile with increasing EGR



Recall no pilot injection on Efficient LTC condition

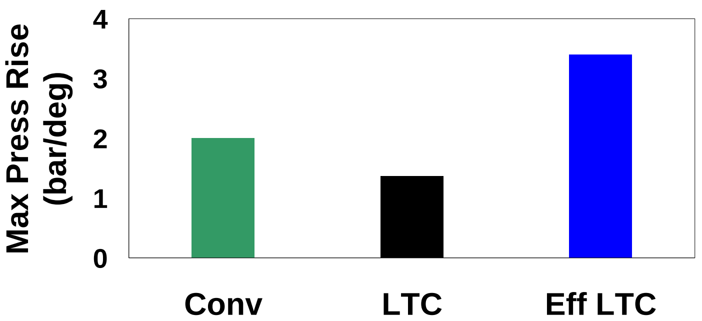
(detailed operating parameters on previous slide)

Recovered condition exhibits shortest 10-50% heat release interval



10-50% 50-90%

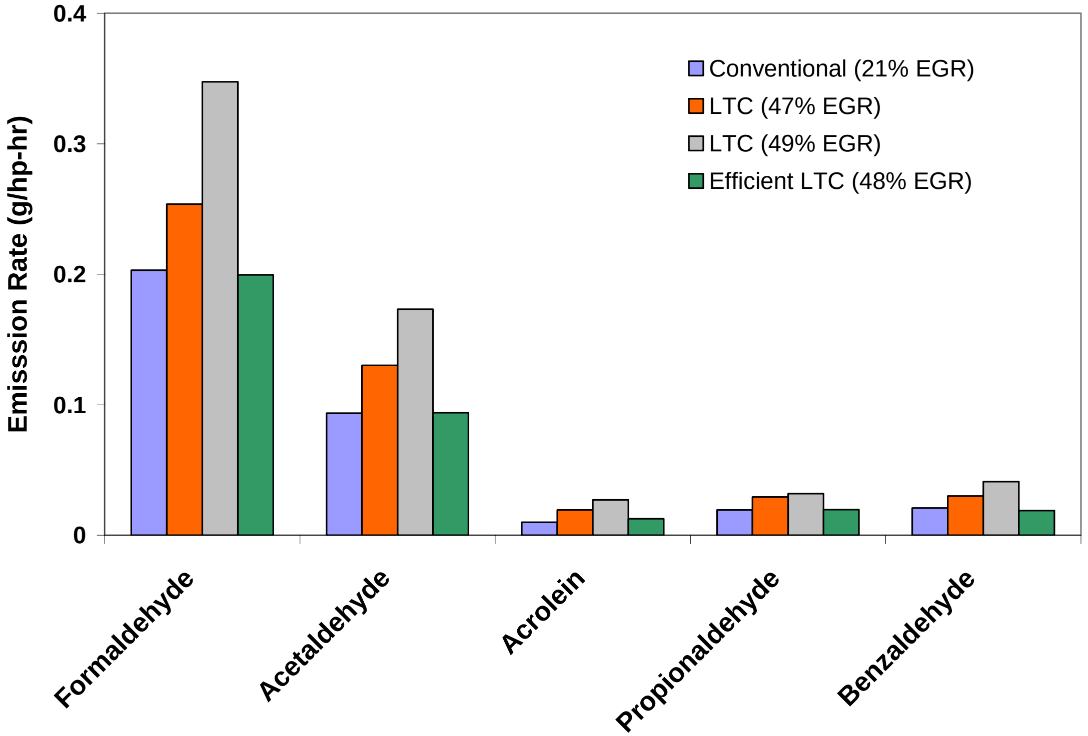
- Recovered 10-50% shorter than baseline case.
- Recovered 50-90% comparable to high EGR condition.
- Trends with mass fraction burned durations.



Other observations from experimental data ...

- Bulk gas temperature (different from flame temperature) does not appear to trend with emissions.
- Bulk gas temperature at SOI increases with EGR.
- COV in IMEP increases with EGR but recovered condition is similar to baseline.
- Cylinder-to-cylinder differences may be result of EGR distribution across the cylinders.
- Discovered compression leak in cylinder 4. Engine replaced and being de-greened.

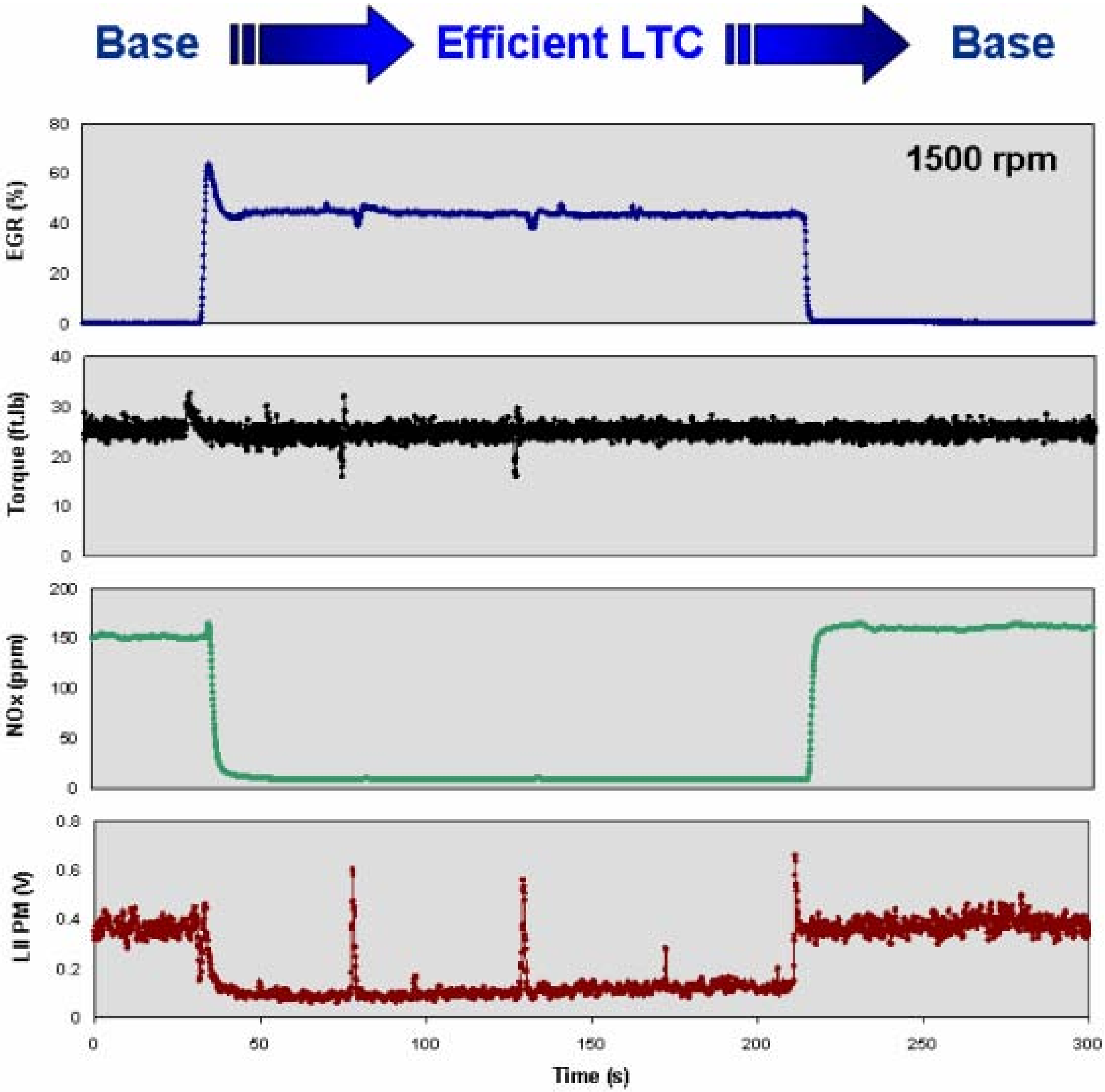
Formaldehyde and acetaldehyde formation for recovered case similar to baseline



Engine maintained performance for the one hour necessary for detailed sampling.

Controlled transition between *conventional* and *efficient LTC* operation

- Controlled transition performed on second Mercedes 1.7-L at ORNL with more advanced control system.
- Transient PM measured with Laser Induced Incadescence (LII) instrument on-loan from Pete Witze of Sandia National Laboratory.
- Similar conditions and recovery method as previously described.



Summary

	Base	E-LTC
EGR (%)	0	44
BSFC (g/hp.hr)	212	212
NOx (ppm)	161	9
LII (volts)	0.39	0.12

Summary/Observations

- LTC achieved with ECD1, CARB, and Certification fuel.
- Ability to recover efficiency under LTC operation is function of transition rate to high EGR.
- After fast transition to high EGR, engine maintains low emissions levels and high efficiency.
- No significant PM spike observed during transitions in and out of efficient LTC operation.
- Formaldehyde and acetaldehyde formation for efficient LTC operation similar to conventional operation.
- Efficient LTC operation characterized by short 10-50% heat release interval as compared to conventional and LTC.
- Transition to efficient LTC operation difficult on this engine under boost conditions.

Future Work

- Low-pressure EGR to attempt to alleviate problems with achieving LTC under boosted conditions.
- More advanced engine control system to improve ability to research transition effects on efficient LTC operation (system identical to existing ORNL controller).
- Partially premixed LTC using Ohio State diesel atomizer.
- More detailed investigation of fuel effects on *efficient* LTC operation.
- Improved thermodynamic analysis through collaborations with universities, industry, and other national laboratories.