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Visualization of In-Cylinder Combustion R&D

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UChicago ▶ Argonne LLC

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Project ID#
ACE011

Overview

Timeline

- Started May 2008
- Ends Sept. 2011
- 50% Complete

Budget

- Total project funding
  - DOE share 100%
  - Contractor share 0%
- Funding received in
  - FY09 $550k
  - FY10 $650k

Barriers

- Barriers addressed
  - Mechanism to control LTC Timing
  - LTC high load and high speed operation
  - LTC control during change of speed and load

Partners

- Argonne is project lead
- Partners are
  - GM Europe and GM R&D
    - Engine maps, piston crowns and other hardware, cylinder head modifications, technical support
  - University of Illinois - Chicago
    - Graduate student performing engine simulations using Converge code
  - BP
    - Several different cetane number fuels,
  - Drivven
    - Controller algorithm upgrades

Objectives of this Study (Relevance)

- Utilize in-cylinder combustion imaging to enable the implementation of low temperature combustion in a production automotive engine
- Focus upon gasoline-like (low cetane) fuels
  - Avoid soot/NO_x production by insuring the end of injection occurs before the start of combustion
  - Diffusion flames show up well in endoscope imaging
  - Fuel/(Air+EGR) will be premixed, but not well mixed – some stratification will enable higher load operation and control of combustion phasing
- Maintain relatively high power densities (~15 bar BMEP) while retaining high efficiency and low emissions
- Control combustion phasing by utilizing in-cylinder controls
  - EGR will be unevenly distributed, as well as cylinder wall temperature
  - Cylinder-to-cylinder control required
  - Use pressure transducer and other sensors for feedback control

Milestones

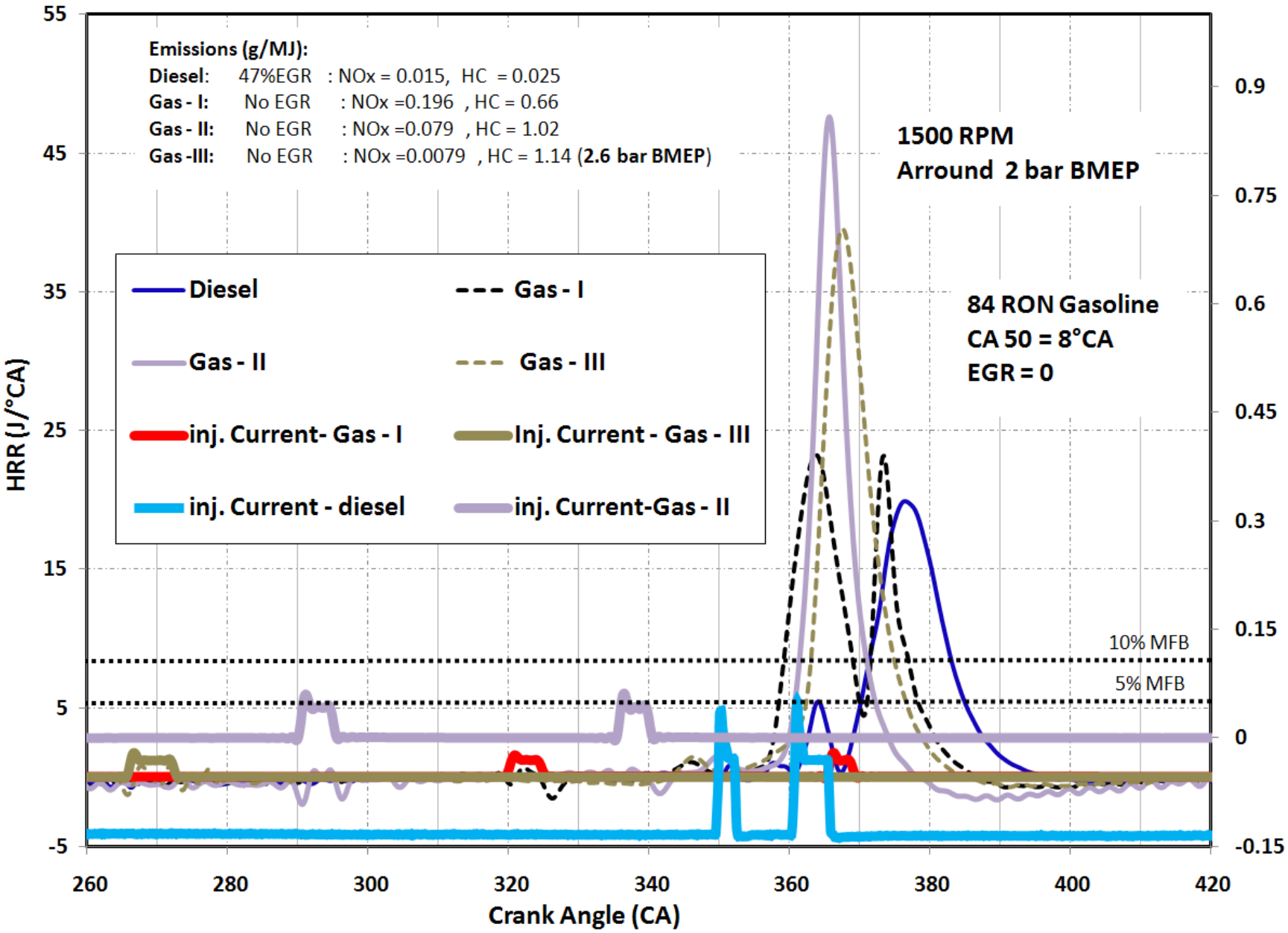
Iso-Paraffinic Kerosene Operation	Dec 2009
85 RON Gasoline Operation	Feb 2010
Same Cycle Control Validated	Mar 2010
Different gasoline injection strategies	Apr 2009
Future milestones	
Operate 75 RON and 65 RON gasoline	Jun 2010
Validate optical access in cylinder head	Jul 2010
Operate first set of lower compression ratio pistons	Aug 2010
Discover LTC operating envelope	Sept 2010

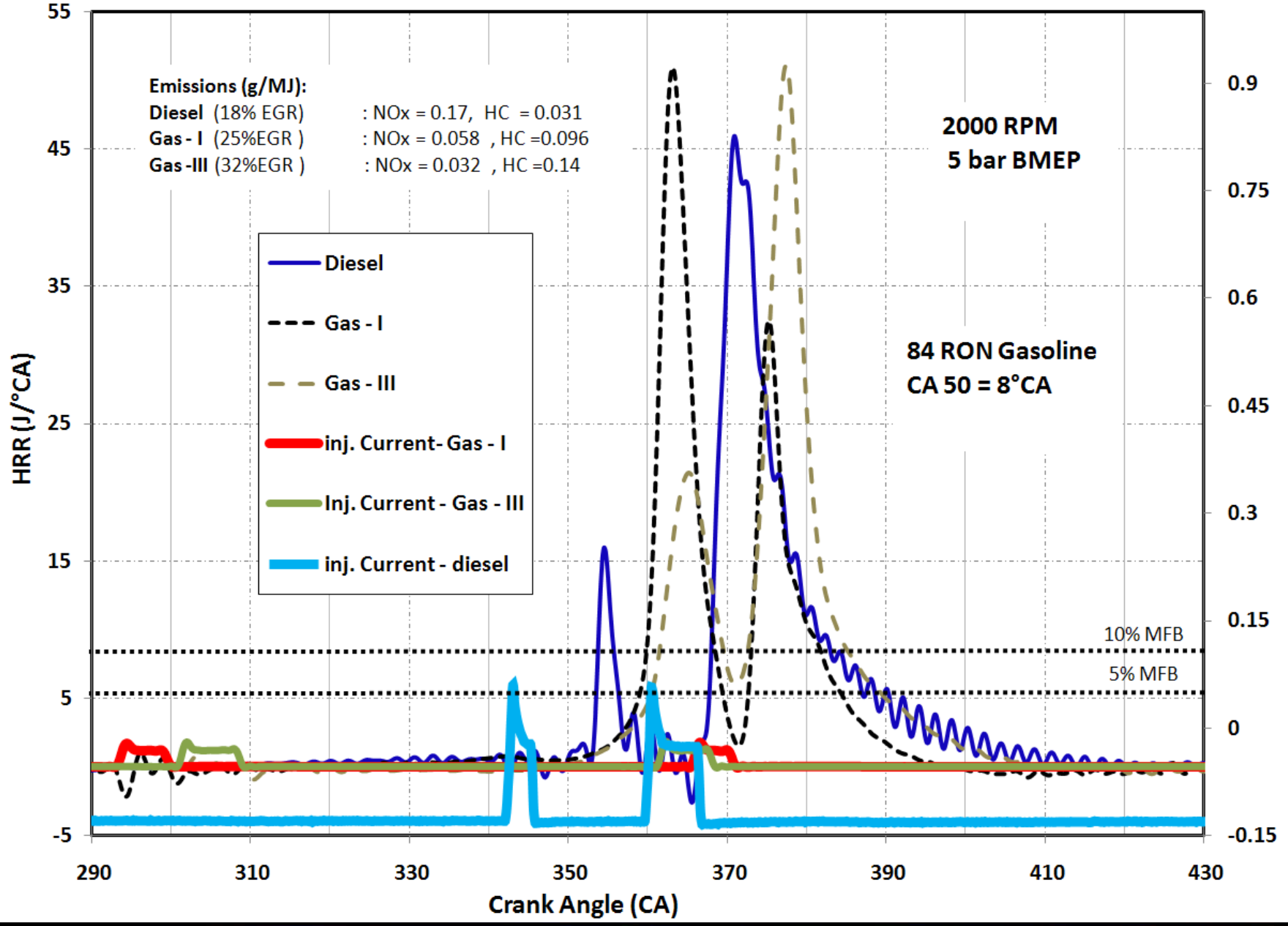
Approach

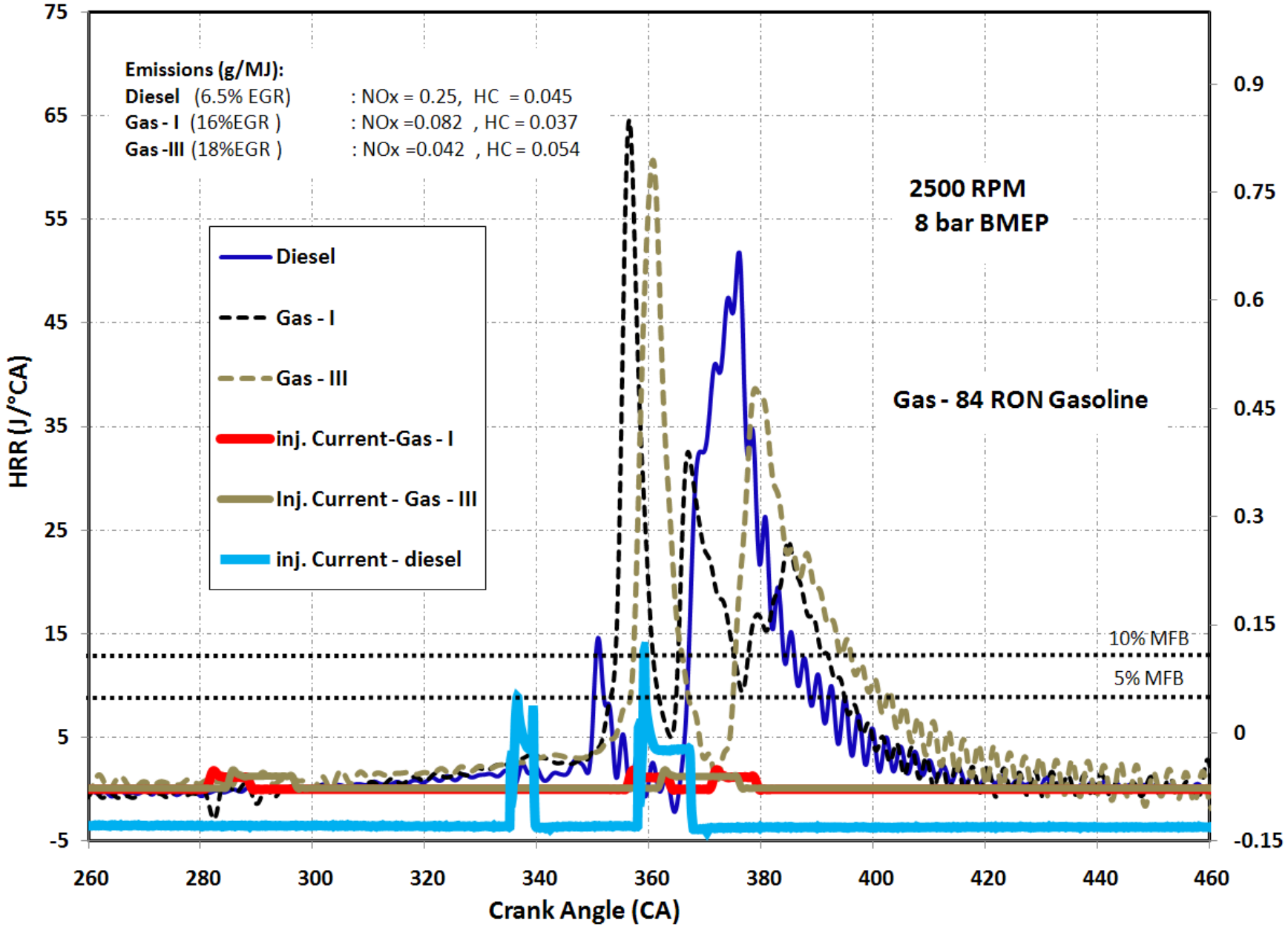
- This project will use low cetane/high volatility fuel
  - Fuel provided by BP Naperville
  - Significantly increase ignition delay
  - Limit/eliminate wall and piston fuel wetting
  - Desired ignition after the end of injection to avoid mixing controlled combustion
  - This approach is different than most other LTC projects!
    - *Little to no EGR, especially at low speed/load*
- Different compression ratio pistons from GM-E (14:1,15:1,16:1,17.5:1)
- Gasoline-like fuels with low cetane/high volatility
- Lubricity additive to insure operation of diesel injection equipment
- Use fluid mechanics to control combustion phasing and engine load
- Use combustion imaging to guide optimal engine parameters and evaluate different fuel combustion characteristics
- Support experimental work with engine simulations from UIC using “Converge” code
- Leverage our APS injector work to better understand diesel injector performance using gasoline-like fuels

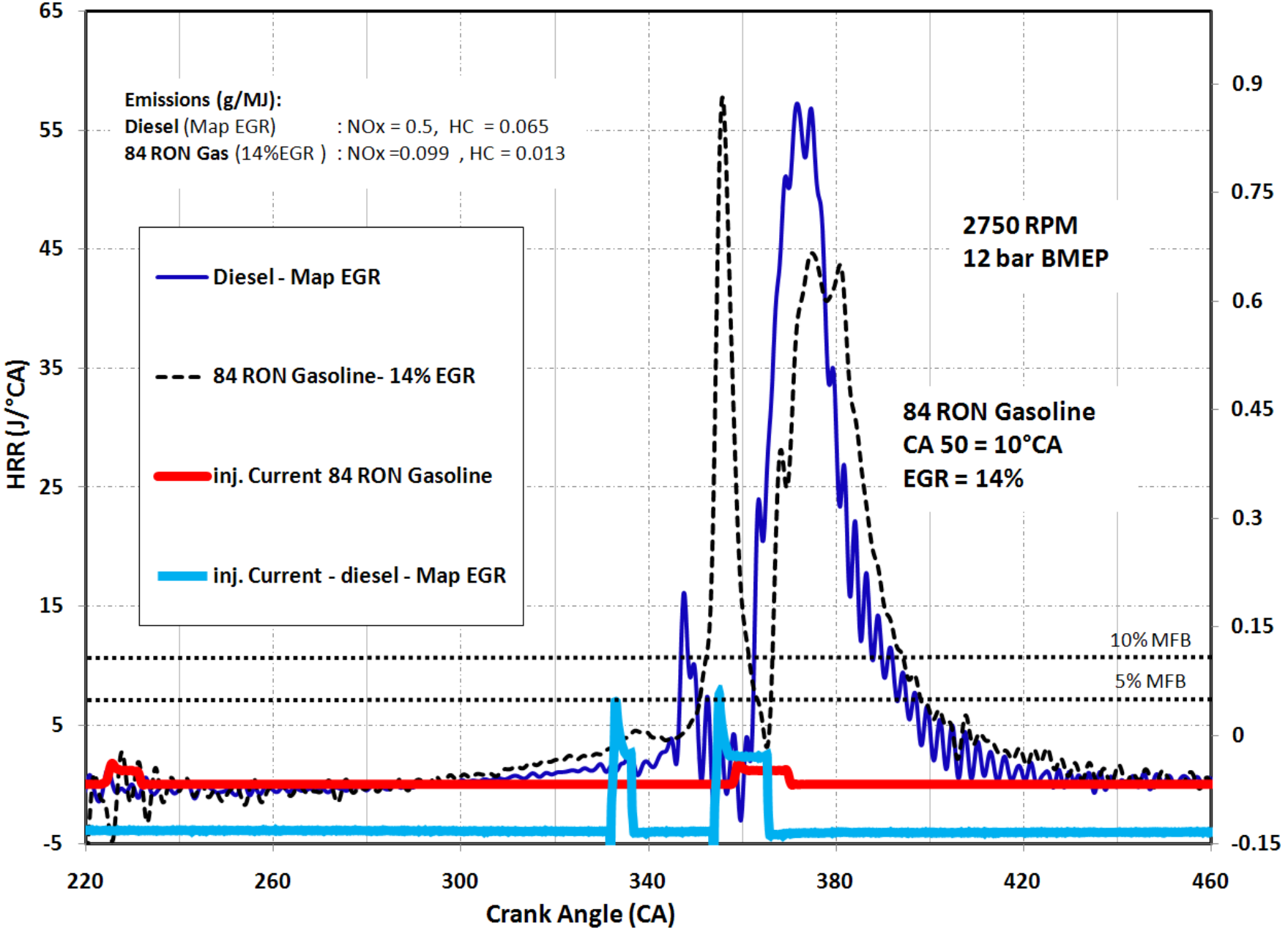
Technical Accomplishments

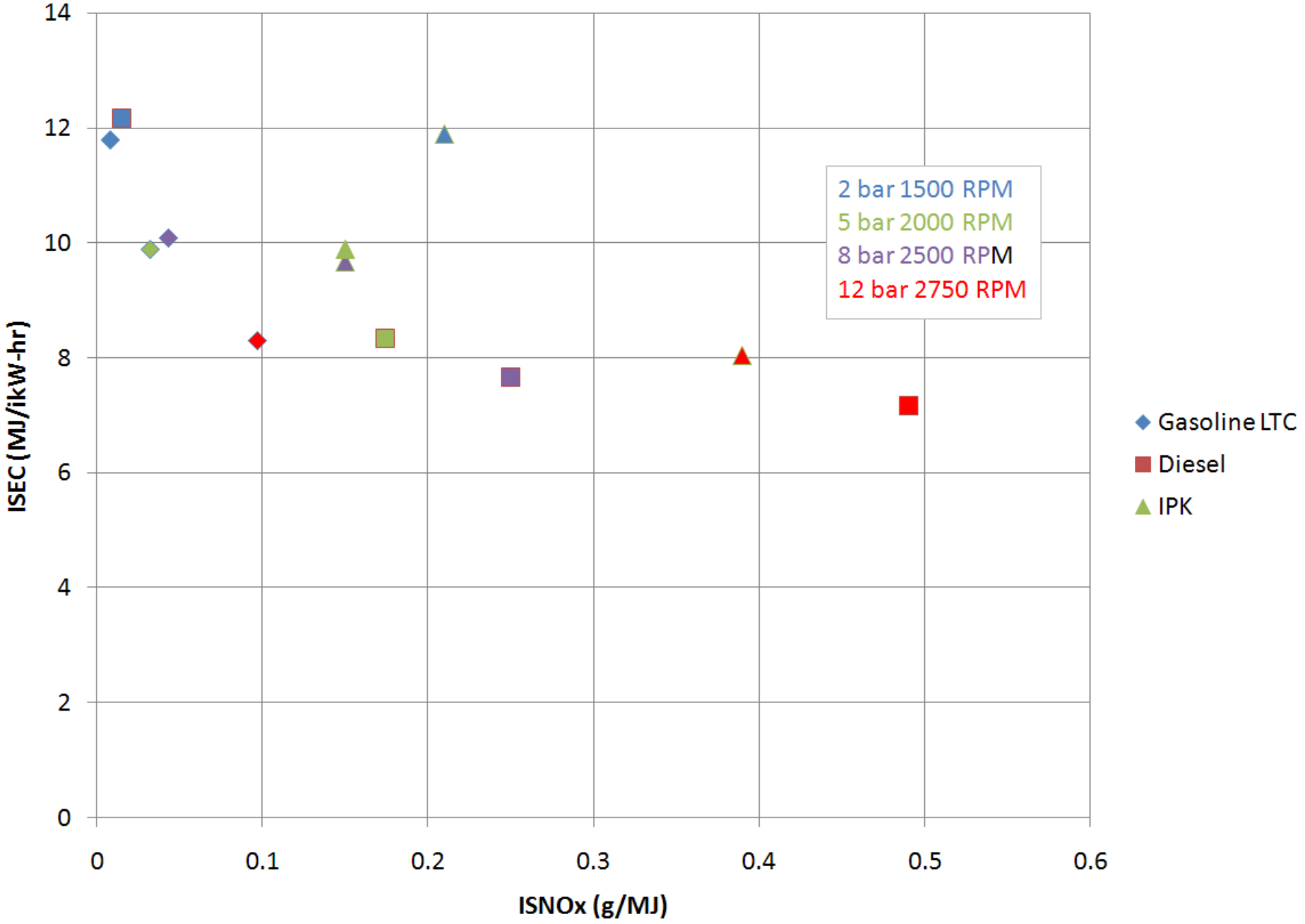
- Successfully operated the engine using low cetane fuels
  - Iso-Paraffinic Kerosene (31-37 cetane based upon standard)
  - 85 RON gasoline
- Very low NO_x emissions levels achieved
- 4 target engine operating conditions
  - 2 bar BMEP at 1500 RPM
  - 5 bar BMEP at 2000 RPM
  - 8 bar BMEP at 2500 RPM
  - 12 bar BMEP at 2750 RPM
- Have successfully operating engine at 16 bar BMEP at 3000 RPM.
- Successfully demonstrated Next Cycle Control and Same Cycle Control.
- Successfully achieved greater than 30% BTE for all operating points

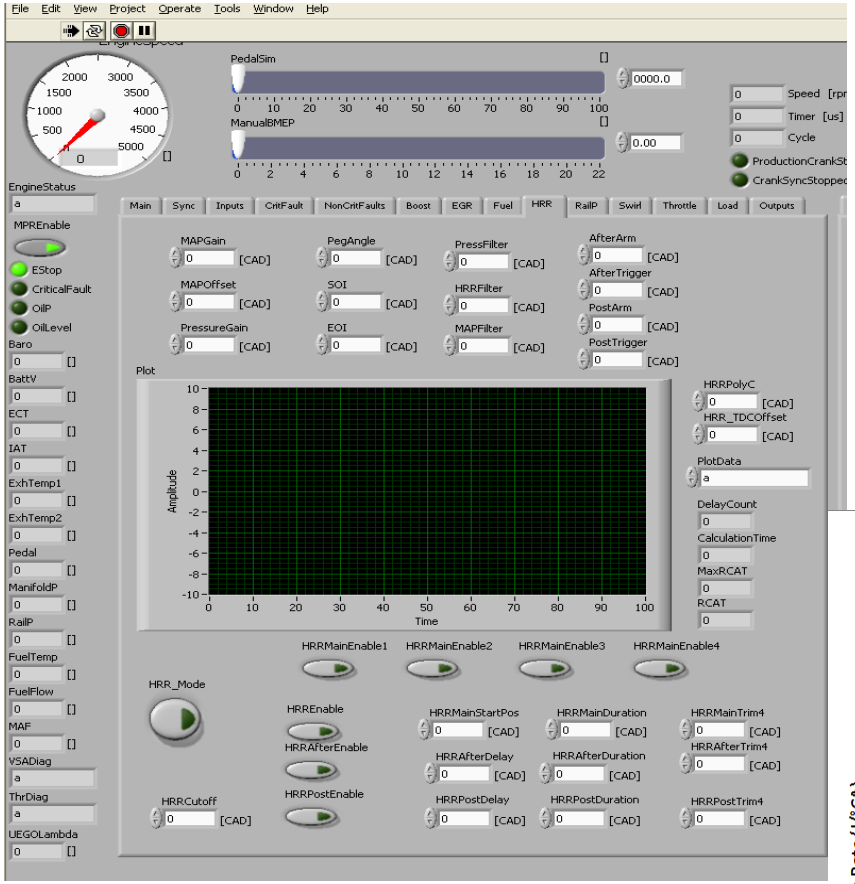

Emissions (g/MJ):
Diesel: 47%EGR : NOx = 0.015, HC = 0.025
Gas - I: No EGR : NOx =0.196 , HC = 0.66
Gas - II: No EGR : NOx =0.079 , HC = 1.02
Gas -III: No EGR : NOx =0.0079 , HC = 1.14 (2.6 bar BMEP)
1500 RPM
Arround 2 bar BMEP
84 RON Gasoline
CA 50 = 8°CA
EGR = 0
Diesel
Gas - I
Gas - II
Gas - III
inj. Current- Gas - I
Inj. Current - Gas - III
inj. Current - diesel
inj. Current-Gas - II
10% MFB
5% MFB
HRR (J/°CA)
Crank Angle (CA)
55
45
35
25
15
5
-5
0.9
0.75
0.6
0.45
0.3
0.15
0
-0.15
260
280
300
320
340
360
380
400
420

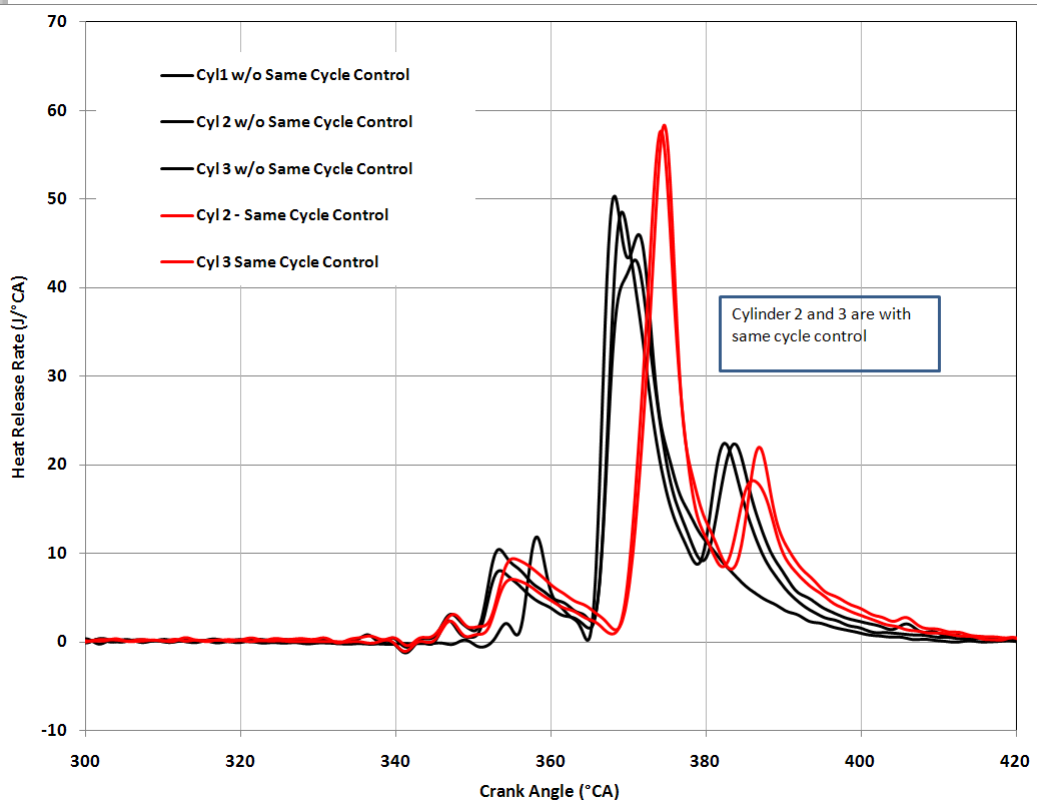

Emissions (g/MJ):
Diesel (18% EGR) : NOx = 0.17, HC = 0.031
Gas - I (25%EGR) : NOx = 0.058 , HC =0.096
Gas -III (32%EGR) : NOx = 0.032 , HC =0.14
2000 RPM
5 bar BMEP
84 RON Gasoline
CA 50 = 8°CA
Diesel
Gas - I
Gas - III
inj. Current- Gas - I
Inj. Current - Gas - III
inj. Current - diesel
10% MFB
5% MFB
HRR (J/°CA)
Crank Angle (CA)
55
45
35
25
15
5
-5
0.9
0.75
0.6
0.45
0.3
0.15
0
-0.15
290
310
330
350
370
390
410
430


Emissions (g/MJ):
Diesel (6.5% EGR) : NOx = 0.25, HC = 0.045
Gas - I (16%EGR) : NOx =0.082 , HC = 0.037
Gas -III (18%EGR) : NOx =0.042 , HC = 0.054
2500 RPM
8 bar BMEP
Gas - 84 RON Gasoline
Diesel
Gas - I
Gas - III
inj. Current-Gas - I
Inj. Current - Gas - III
inj. Current - diesel
10% MFB
5% MFB
HRR (J/°CA)
Crank Angle (CA)
75
65
55
45
35
25
15
5
-5
0.9
0.75
0.6
0.45
0.3
0.15
0
-0.15
260
280
300
320
340
360
380
400
420
440
460


Emissions (g/MJ):
Diesel (Map EGR) : NOx = 0.5, HC = 0.065
84 RON Gas (14%EGR) : NOx =0.099 , HC = 0.013
Diesel - Map EGR
84 RON Gasoline- 14% EGR
inj. Current 84 RON Gasoline
inj. Current - diesel - Map EGR
2750 RPM
12 bar BMEP
84 RON Gasoline
CA 50 = 10°CA
EGR = 14%
10% MFB
5% MFB
HRR (J/°CA)
Crank Angle (CA)
65
55
45
35
25
15
5
-5
0.9
0.75
0.6
0.45
0.3
0.15
0
-0.15
220
260
300
340
380
420
460


14
12
10
8
6
4
2
0
ISEC (MJ/iKW-hr)
0
0.1
0.2
0.3
0.4
0.5
0.6
ISNOx (g/MJ)
2 bar 1500 RPM
5 bar 2000 RPM
8 bar 2500 RPM
12 bar 2750 RPM
Gasoline LTC
Diesel
IPK


File Edit View Project Operate Tools Window Help
PedalSim
ManualBMEP
EngineStatus
MPREnable
EStop
CriticalFault
OilP
OilLevel
Main Sync Inputs CritFault NonCritFaults Boost EGR Fuel HRR RailP Swirl Throttle Load Outputs
MAPGain
PegAngle
PressFilter
AfterArm
AfterTrigger
PostArm
PostTrigger
MAPOffset
SOI
HRRFilter
PressureGain
EOI
MAPFilter
Plot
Amplitude
Time
HRRPolyC
HRR_TDCOffset
PlotData
DelayCount
CalculationTime
MaxRCAT
RCAT
HRRMainEnable1
HRRMainEnable2
HRRMainEnable3
HRRMainEnable4
HRR_Mode
HRREnable
HRRAfterEnable
HRRPostEnable
HRRMainStartPos
HRRMainDuration
HRRMainTrim4
HRRAfterDelay
HRRAfterDuration
HRRAfterTrim4
HRRPostDelay
HRRPostDuration
HRRPostTrim4
HRRCutoff


Cyl1 w/o Same Cycle Control
Cyl 2 w/o Same Cycle Control
Cyl 3 w/o Same Cycle Control
Cyl 2 - Same Cycle Control
Cyl 3 Same Cycle Control
Cylinder 2 and 3 are with same cycle control
Heat Release Rate (J/°CA)
Crank Angle (°CA)

Future Work

- Validate engine operation on lower cetane gasoline fuel
  - 75 RON and 65 RON
  - FACE fuel (~30 cetane)
- Validate test matrix using lower compression ratio pistons to achieve NO_x reduction with less EGR
- When LTC operation is determined, use combustion imaging to obtain detailed fluid mechanics and chemistry information
  - Spectroscopic measurements
  - Any possible soot radiation
- Fine-tune combustion phasing control by use of multiple injections, EGR and boost.
- Correlate results with APS spray data and with SNL's fundamental combustion work
  - We are all using identical hardware (Bosch Gen II)
  - Make data available to Engine Combustion Network (managed by SNL; Lyle Pickett)

Summary

- Power density needs to be addressed in LTC operation
- Fluid mechanics is a more robust control parameter than fuel chemistry
- Project has already demonstrated that low cetane fuels can decrease the fuel sensitivity for LTC by utilizing injection parameters for combustion phasing
- Cylinder to cylinder control should be helpful due to lack of even EGR distribution
- Combustion imaging is a very familiar and well-validated tool to help us understand the characteristics of LTC
  - Will be simultaneously with pressure transducers, current clamps, emissions bench, fast FID and fast NO_x analyzers
- Working with GM (and USAF) allows for a rapid path for Technology Transfer
  - Monthly GM teleconferences and scheduled visits