DOE Merit Review
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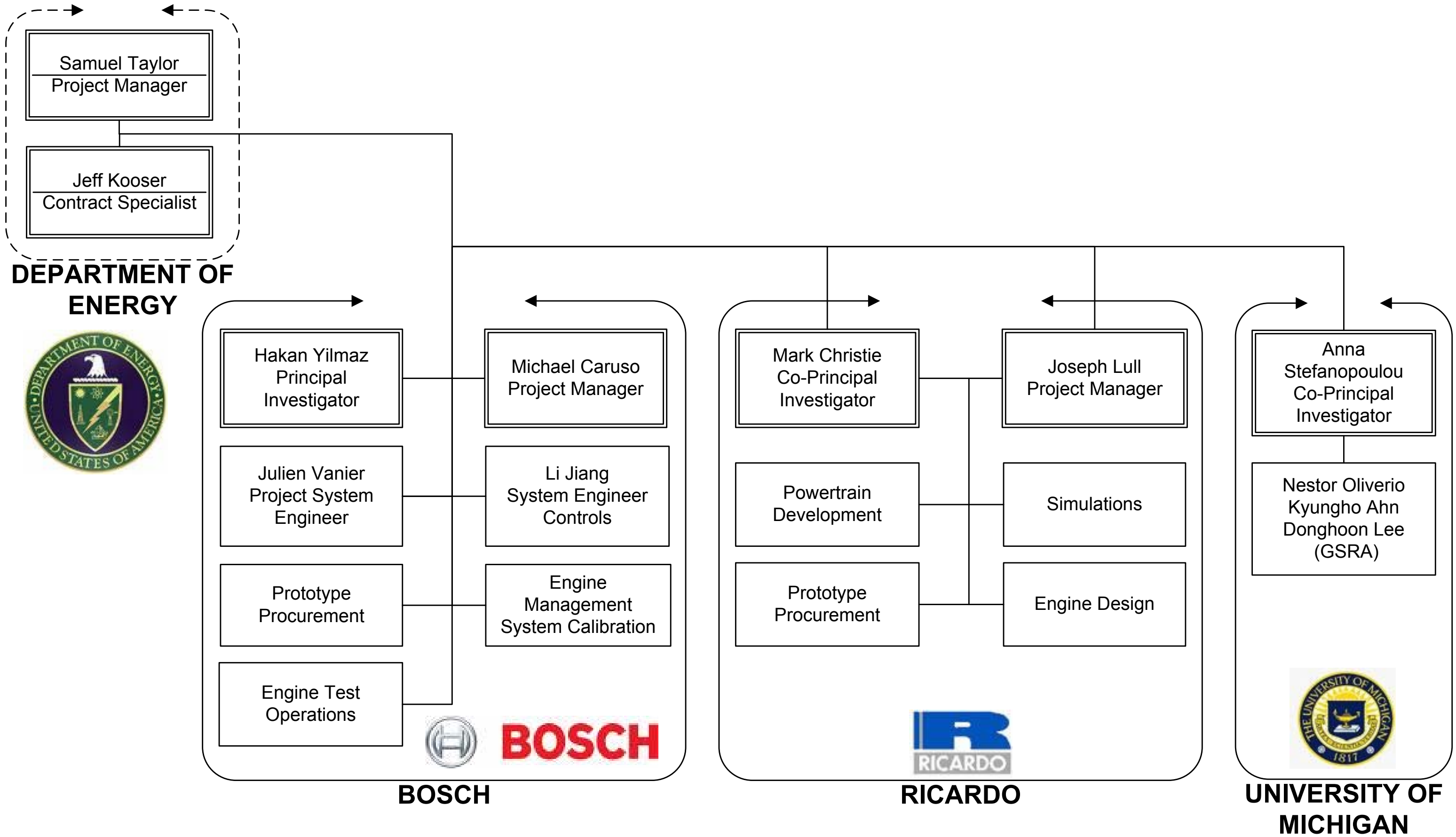
Contract: DE-FC26-07NT43274 *Project ID: ft_13_yilmaz*

"This presentation does not include any confidential material"

- Project Overview
- Barriers and Approach
- Accomplishments and Next Steps

Advanced FFV – Project Organization



DOE Merit Review – Flex Fuel Vehicle Systems

Timeline

- **Start** – October 2007
- **Finish** – September 2010
- **50% complete**

Barriers & Targets

- Barriers
  - Powertrain optimization constraints for FFVs
  - High application effort for different fuels
  - Cost and complexity of ethanol detection
- Targets
  - 10% fuel efficiency improvement with E85
  - ULEV level emissions with E85
  - Ethanol detection, accuracy<5%, time<1 min)

Budget

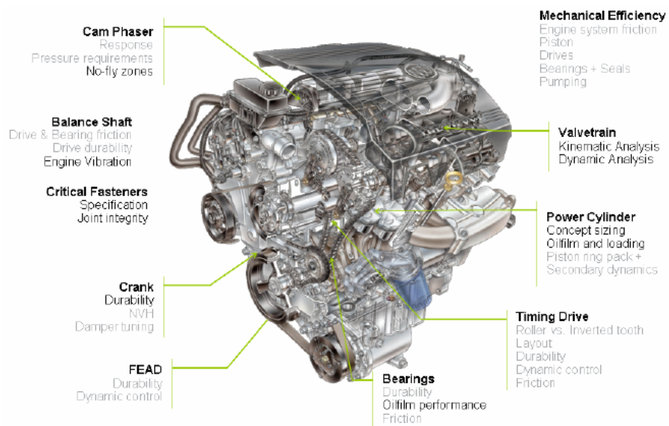
- Total project funding
  - DOE - $1,849K
  - Contractor - $2,099K
- Funding received to date – $890K
- FY2009 DOE - $554K

Partners

- Robert Bosch LLC
- Ricardo, Inc
- University of Michigan, Ann Arbor

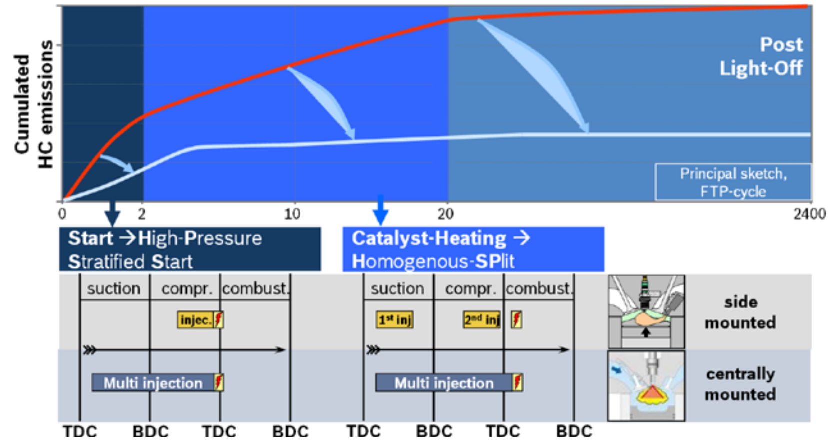
E85 DOE Merit Review – Flex Fuel Vehicle Systems

Engine Optimization for Gasoline & Ethanol

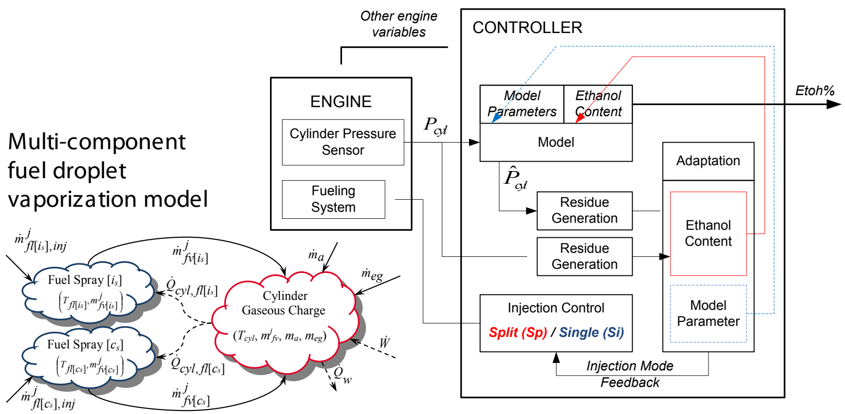


GM Ecotec 2.0 L I4 GDI – VVT – TC – Increased PMAX and Compression Ratio

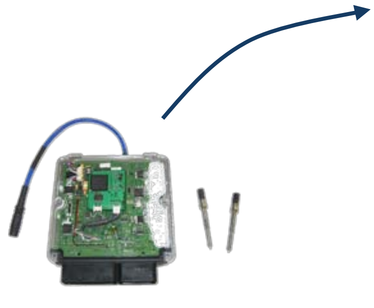
DI System Concept for Emissions

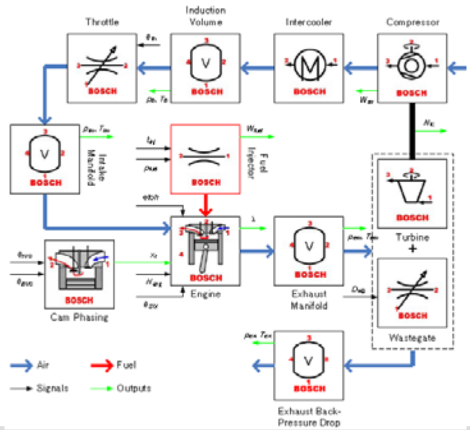


Ethanol Detection via PS-C

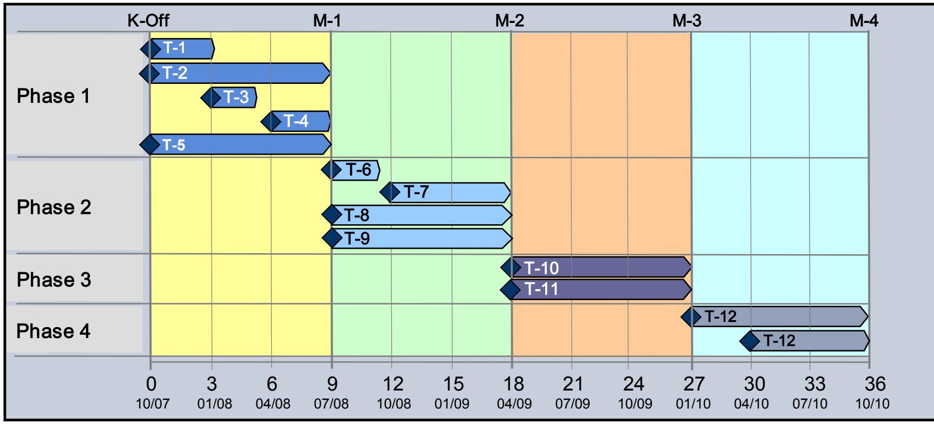


Model Based Controls via PS-C





Advanced FFV – Project Timeline



<u>Task 1</u> – Combustion Concept Design
<u>Task 2</u> – Modeling for Control Strategies
<u>Task 3</u> – Performance Model Simulation
<u>Task 4</u> – Vehicle Simulation Study
<u>Task 5</u> – Base Level Engine Control Unit Integration
<u>Task 6</u> – System Specification
<u>Task 7</u> – Design of Modified Engine Components
<u>Task 8</u> – Development of Base Engine and Powertrain Management Systems
<u>Task 9</u> – Base Level Vehicle Platform Development
<u>Task 10</u> – Procurement and Adaptation of Hardware
<u>Task 11</u> – Control Strategies for Engine and Powertrain Management System
<u>Task 12</u> – Engine Management Software Development
<u>Task 13</u> – Base Engine Application

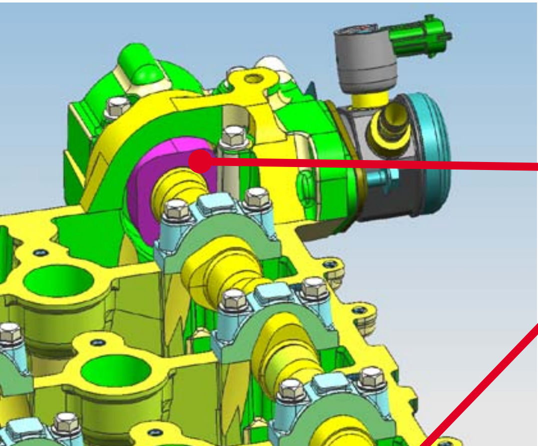
- Project Overview
- **Barriers and Approach**
- Accomplishments and Next Steps

Advanced FFV – Fuel Efficiency and Performance

- **Goal**:
  - Optimized engine design for improved combustion performance
  - Hardware structural robustness for all fuel blends
  - Minimized fuel economy penalty due to increased ethanol content
  - Enhanced performance through exploitation of fuel properties

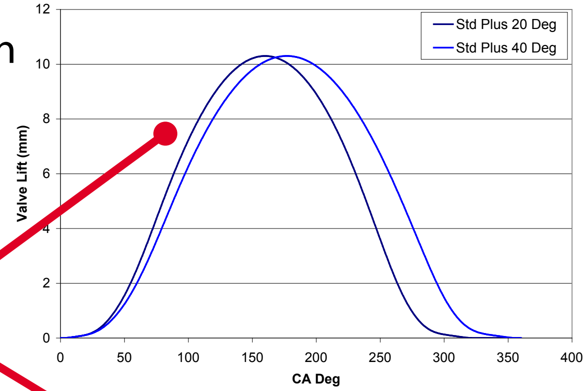
- **Barriers**:
  - Engine hardware
    - peak cylinder pressure capability restricts E85 performance
    - volumetric compression optimized for gasoline only
    - additional NVH measures necessary for E85 combustion
  - Engine management system
    - fuel system pressure not sufficient for high ethanol content
    - injection dynamic flow rate optimized for gasoline
    - boost / VVT systems require optimization for ethanol

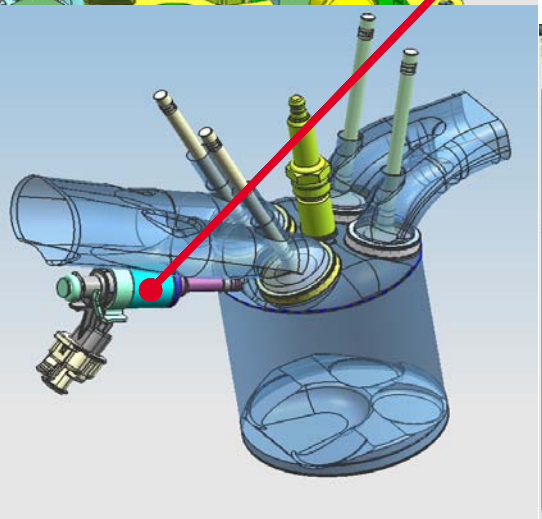
Advanced FFV – Fuel Efficiency and Performance

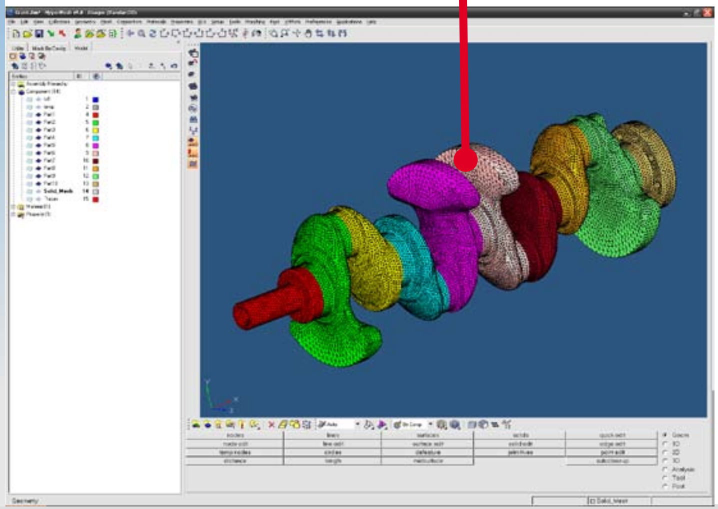


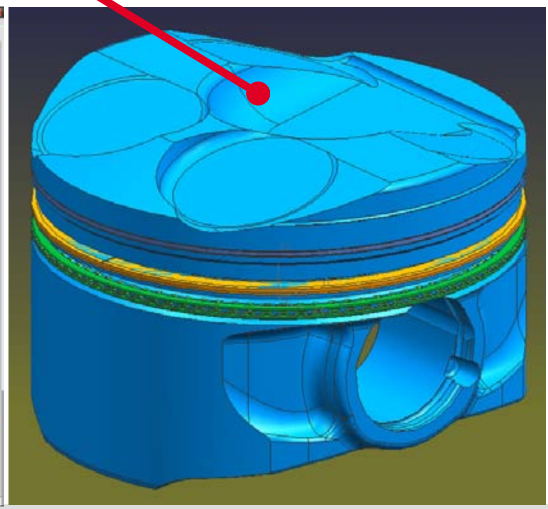
Approach: Engine Optimization

- Larger Fuel Pump
- Revised Fuel Spray
- Late Intake Valve Closing
- High Compression Ratio
- Revised Piston Bowl
- 140 Bar Pmax

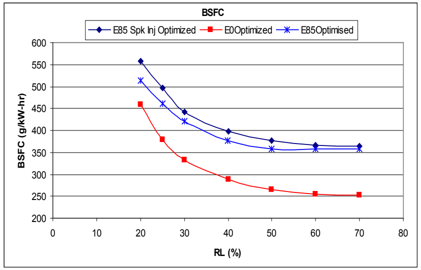


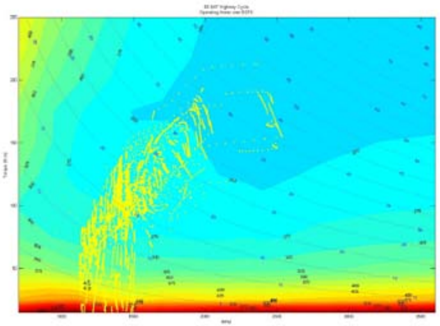


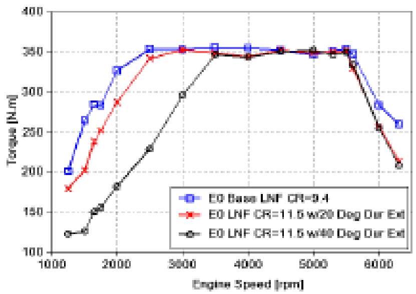




Advanced FFV – Fuel Efficiency and Performance







➔ **Methodology:**

Fuel Efficiency Improvement:

Methodology	Fuel Efficiency Improvement
Optimized part load calibration	2 – 2.5%
Transmission shift pattern f{Exx}	2 – 5 %
High Compression ratio + LIVC	3 – 4 %

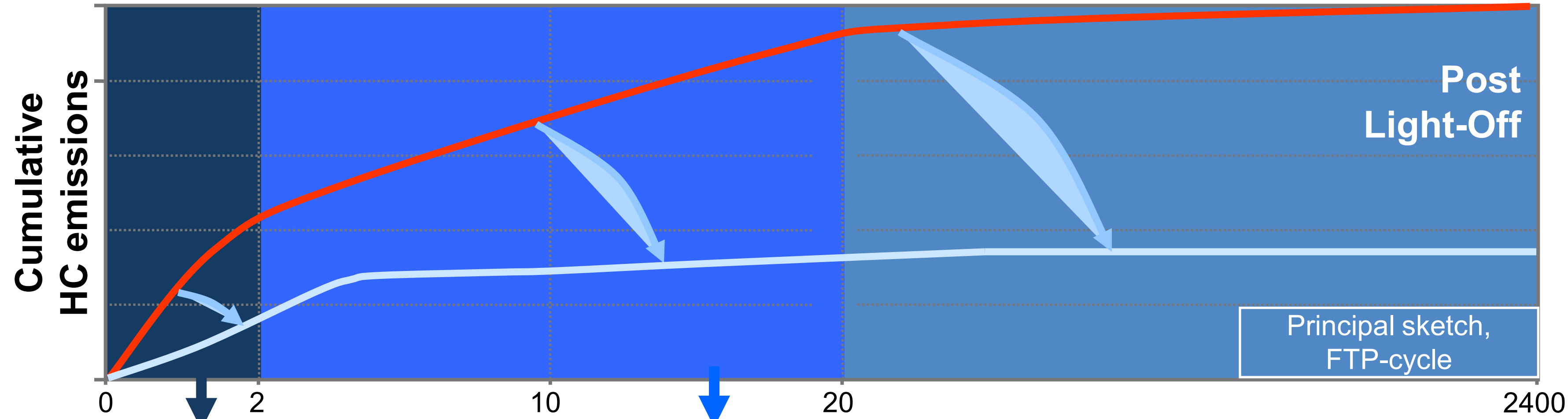
Advanced FFV – Emissions

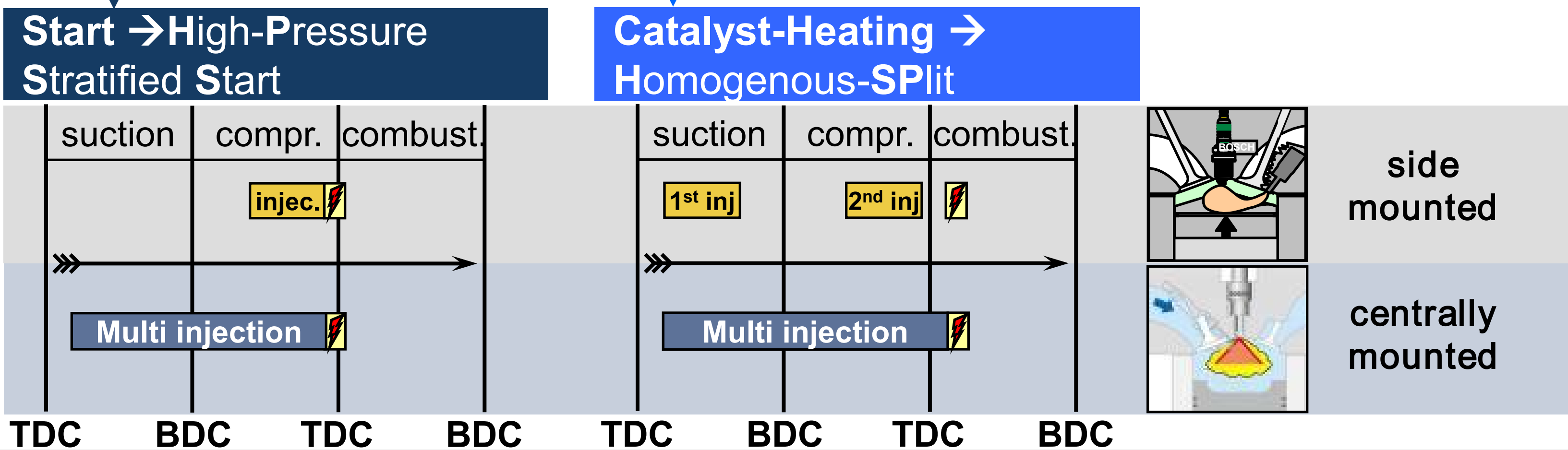
- **Goal**:
  - Achieve ULEV emission levels with all fuel blends E0..E85
  - Define potential path to reach SULEV
  - Optimized combustion design for different fuels
  - No additional after-treatment system complexity

- **Barriers**:
  - Cold starts with E85
    - significantly higher ethanol injection quantity resulting in increased HC
    - delayed catalyst heating due to higher water concentration

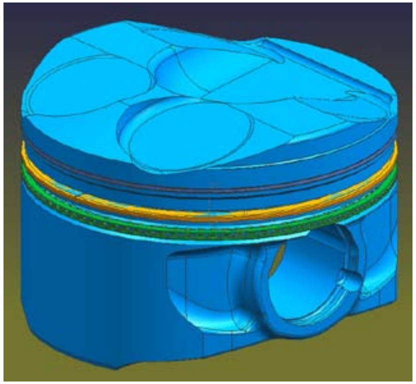
  - Increased wall wetting and oil contamination with increased ethanol content
    - increased HC emissions and smoke

Advanced FFV – Emissions – Approach



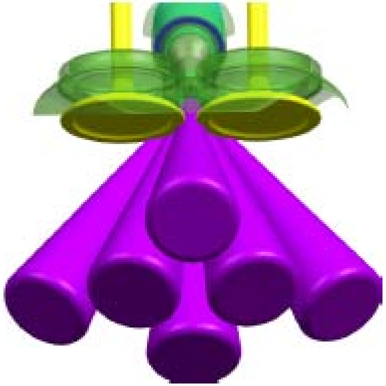


Advanced FFV – Emissions



➔ **Methodology:**

- Piston bowl design for HC emission reduction
  - increased bowl width for improved air/fuel mixture
  - optimized fuel spray deflection angles
  - smoother surface transitions
  - decreased crevice volumes



- Injector design
  - spray targeting for fuel mixture preparation
  - alignment features added for installation
- Injection Strategies
  - high pressure stratified start
  - advanced catalyst heating with homogenous split

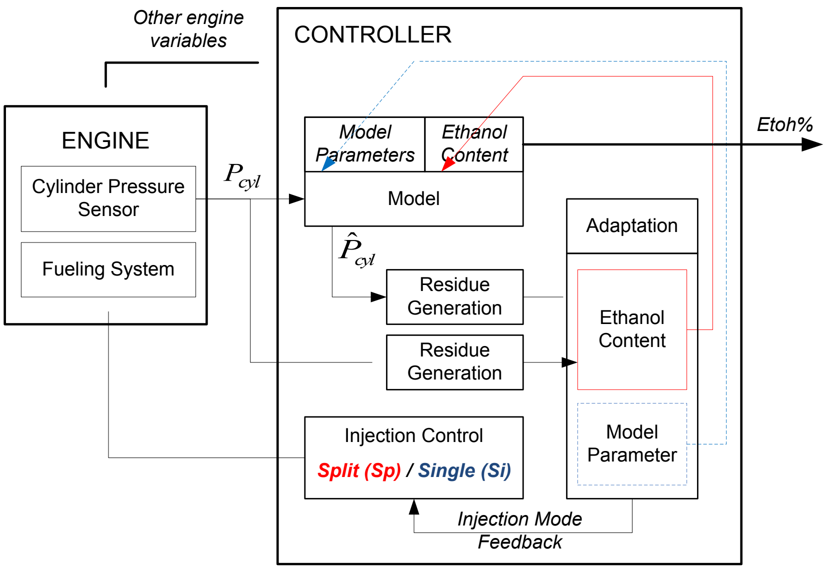
Advanced FFV – Ethanol Content Estimation

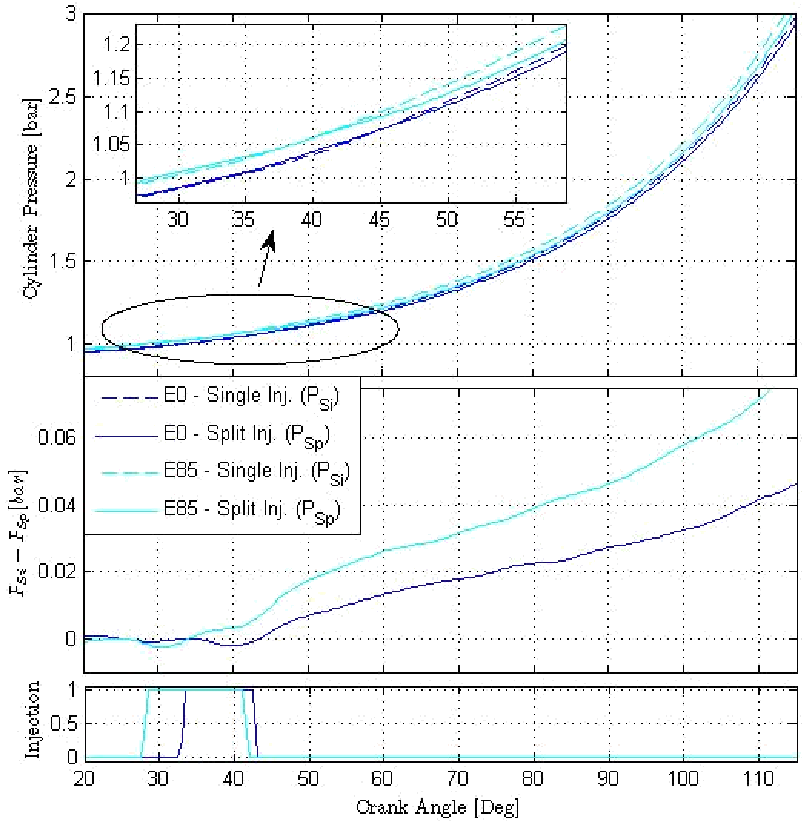
- **Goal**:
  - Develop a systematic approach to achieve an accurate, robust, and fast ethanol content estimation for engine performance optimization, even in the presence of component aging and sensor drifts

- **Barriers**:
  - Direct measurement from Ethanol sensor on fuel line
    - additional cost and system complexity
  - Indirect estimation by Exhaust Gas Oxygen (EGO) sensor
    - sensitive to mass airflow sensor drift and fuel system failures
    - requires coordination of fuel system and ethanol content adaptation
  - Indirect estimation by Cylinder Pressure Sensor (PS-C):
    - robustness and accuracy has not been addressed for combustion and heat release based detection

Advanced FFV – Ethanol Content Estimation

- **Approach**: extract the *charge cooling effects* of various gasoline-ethanol fuels, directly injected during the compression stroke, from cylinder pressure measurements

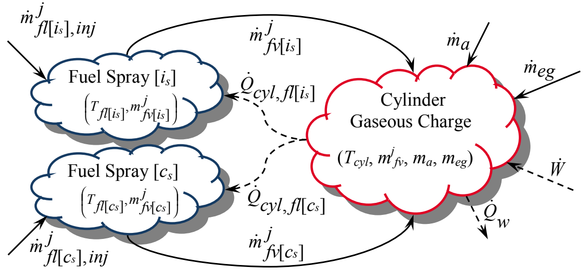


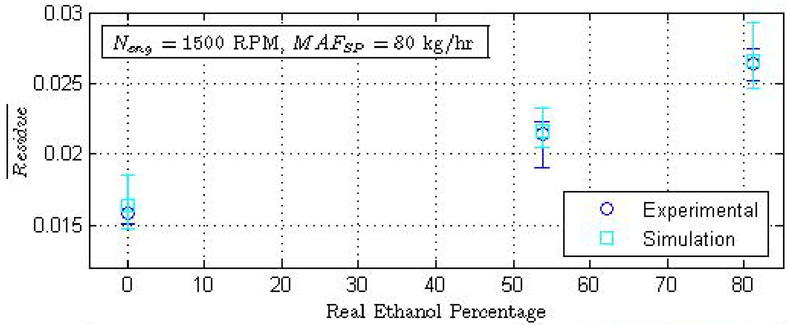


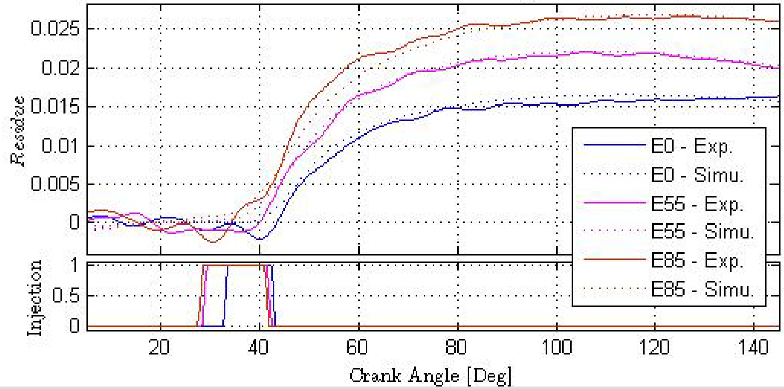
BOSCH

Advanced FFV – Ethanol Content Estimation

- **Methodology:**
  - Fuel droplet vaporization model
  - Injection mode control - single / split
  - Residue generation







Preliminary Empirical Results

	E0	E40	E55	E70	E85
2500RPM, 170kg/h					
Estimated EXX	1.71	35.35	56.34	65.52	84.23
Error EXX	1.71	-4.65	3.04	-2.23	2.13
2500RPM, 130kg/h					
Estimated EXX	-3.14	41.02	59.73	64.28	78.76
Error EXX	-3.14	2.53	6.73	-3.22	-2.90
2000RPM, 150kg/h					
Estimated EXX	-0.34	40.75	49.71	69.56	83.79
Error EXX	-0.34	2.49	-3.94	2.06	-0.28
2000RPM, 100kg/h					
Estimated EXX	-5.77	45.51	59.02	68.60	76.82
Error EXX	-5.77	7.49	4.20	1.11	-7.04

Advanced FFV – Engine Controls

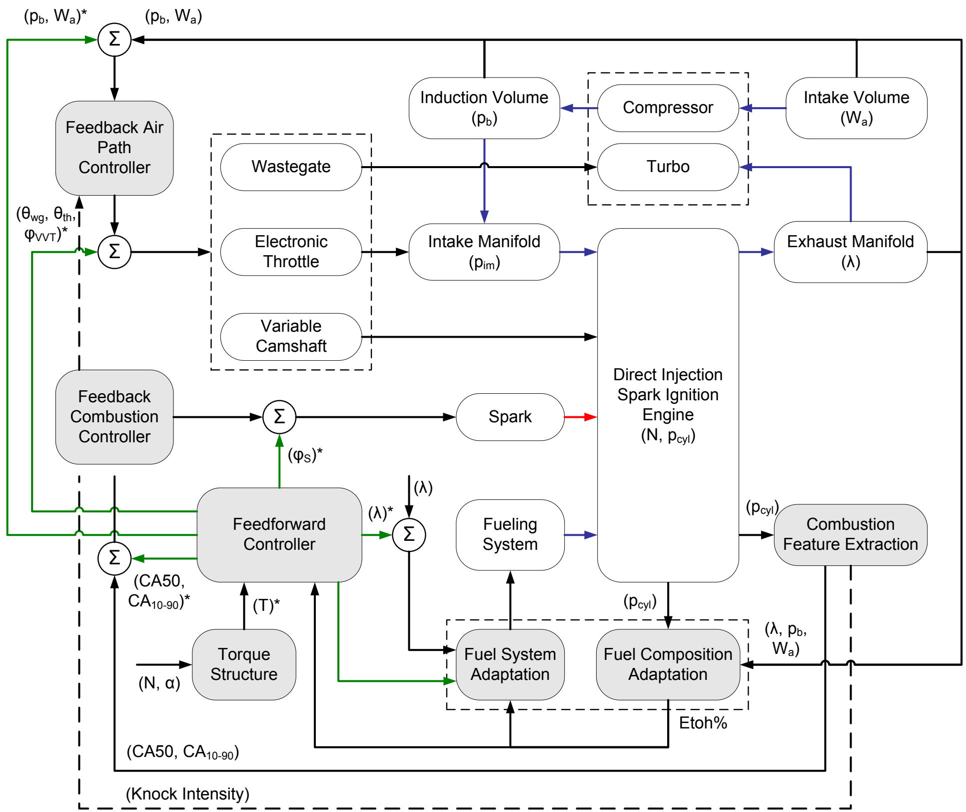
- **Goal**:
  - Optimized engine controls for all fuel blends
  - Robust and fast adaptation of engine control parameters
  - Minimum additional calibration effort

- **Barriers**:
  - Current engine controllers adjust the spark and fuel injection timing, variable valve timing and boost in a feedforward manner
    - significant additional calibration efforts for different fuel blends
    - deviation from optimal calibration due to interpolation inaccuracies
    - lack of coordinated control of air path during speed/load transients

Advanced FFV – Engine Controls

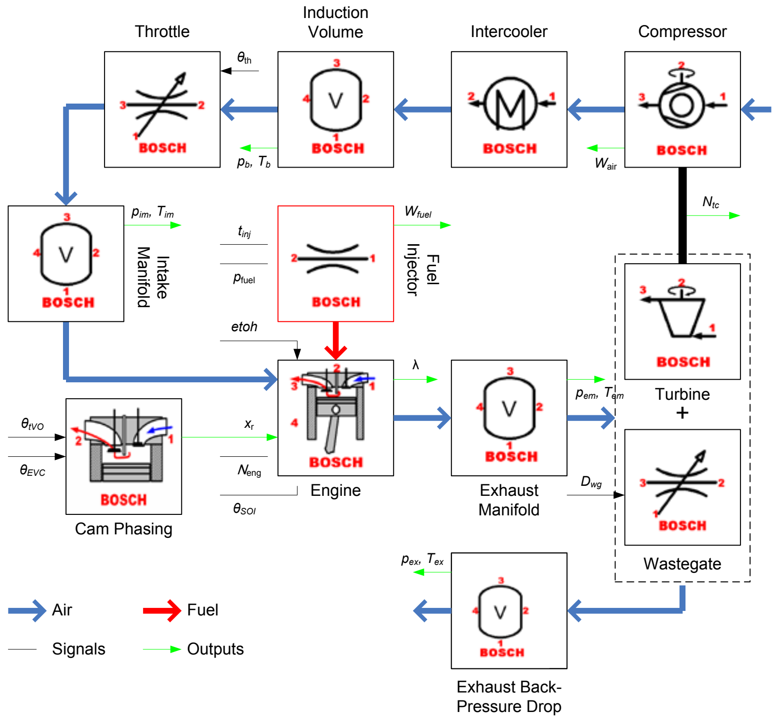
- **Approach**: model-based close-loop control of combustion events via cylinder pressure sensors

- **Methodology**:
  - In-cylinder pressure sensor based closed-loop combustion control via spark timing decoupled from ethanol content
  - Optimized EGR control via VVT during part load transients
  - Coordination of electronic throttle, turbo charger waste-gate, and VVT system in boosted regions



Advanced FFV – Engine Controls

- **Methodology**:
  - control-oriented mean-value engine model development
  - Engine Control Unit development on Bosch MED17
    - base-level engine control algorithms with component packages
    - flex-fuel capable platform
    - cylinder pressure sensing



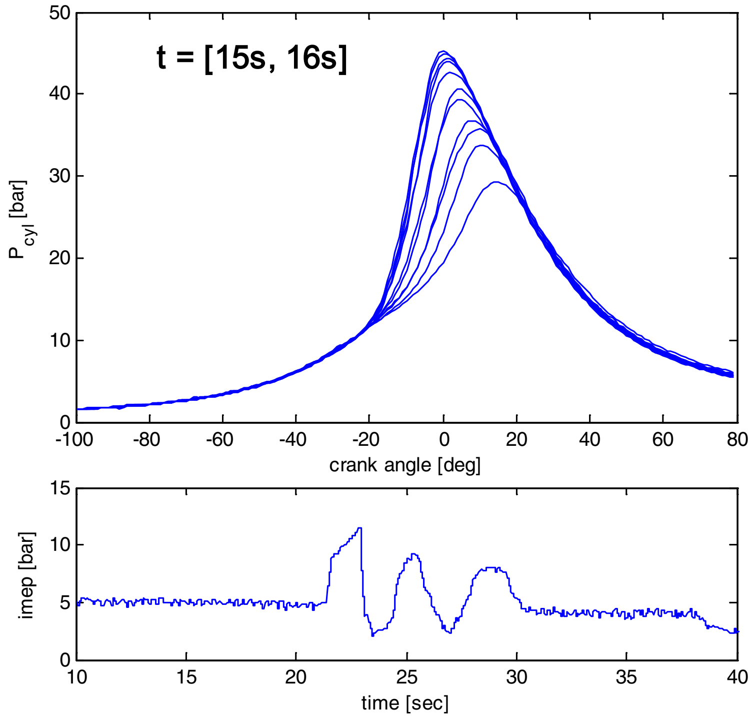
Cylinder Pressure Adapted Board

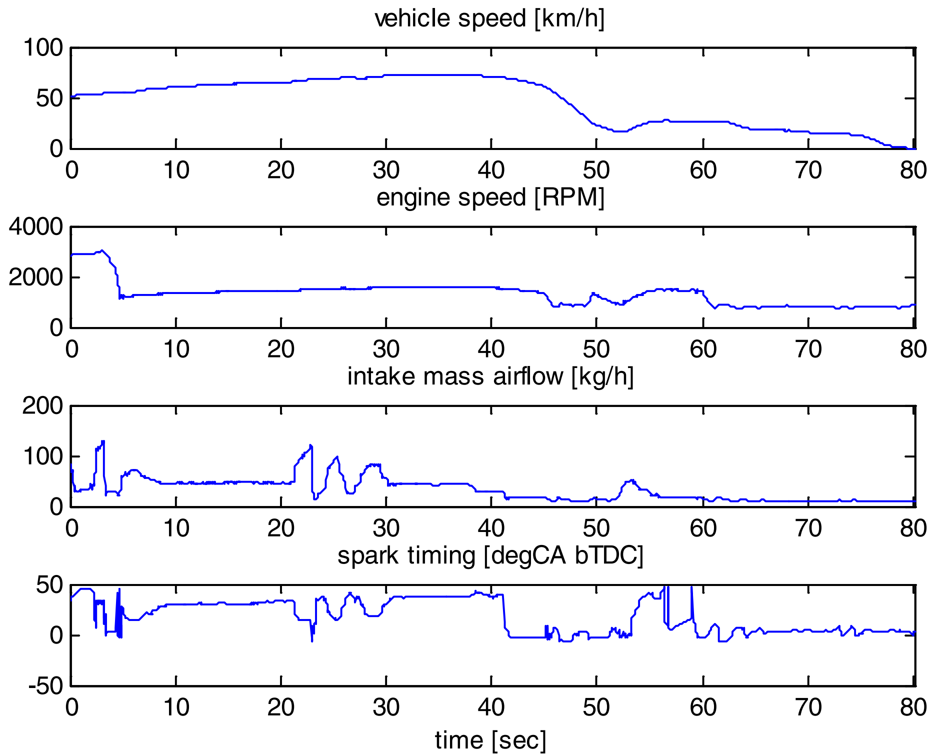
Bosch Cylinder Pressure Sensor

Advanced FFV – Engine Controls

→ **Methodology**: Engine Control Unit development on Bosch MED17

- vehicle-level calibration and integration (Chevrolet HHR)





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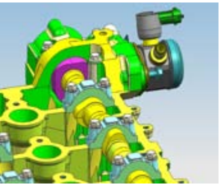
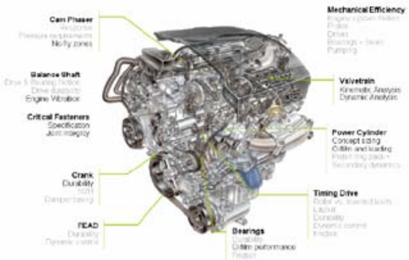
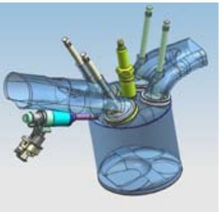
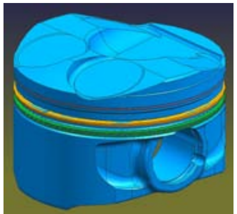
DOE Merit Review – Flex Fuel Vehicle Systems

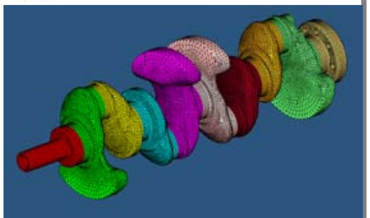
Fuel Efficiency and Performance











Approach

- Increase maximum cylinder peak pressure
- Optimize volumetric compression ratio
- Increase fuel rail pressure
- Enlarge Injector dynamic flow rate
- Enable late intake valve closing

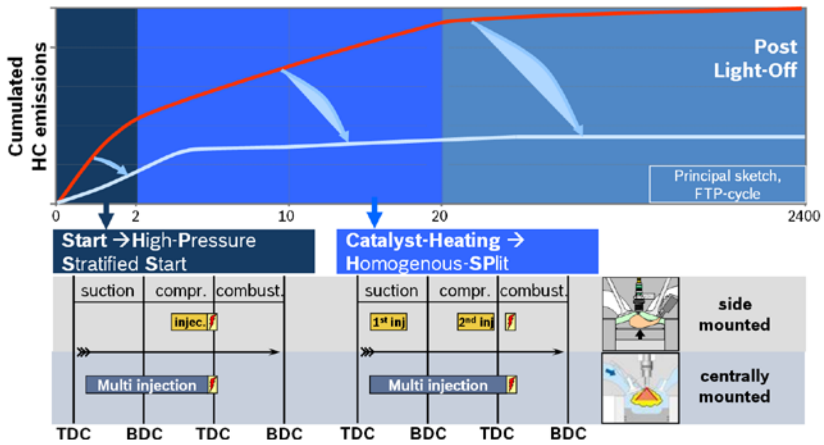
Status

- ✓ Specification of induction and fuel system
- ✓ Engine hardware design for PMAX 140 Bar
- ✓ Engine hardware design for ethanol fuels
- ✓ Cam shaft profile specification for LIVC
- ✓ Piston design for increased compression ratio

Next Steps

- Prototype hardware procurement
- Integration of engine and vehicle hardware
- Engine parameterization with new hardware

Emissions



Approach

- Piston bowl design for HC emission reduction
- Spray targeting for fuel mixture preparation
- High pressure stratified start
- Advanced catalyst heating with homogenous split

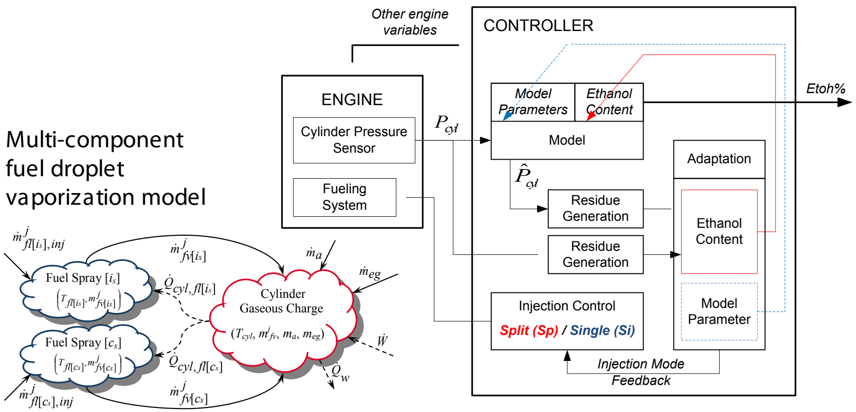
Status

- ✓ Increased bowl width for improved mixture
- ✓ optimized fuel spray deflection angles
- ✓ smoother surface transitions
- ✓ decreased crevice volumes
- ✓ Spray targeting for fuel mixture preparation

Next Steps

- Engine hardware procurement
- DI injection system integration
- High pressure stratified start implementation
- Advanced catalyst heating with homogenous split

Ethanol Content Estimation via PS-C



Approach

- Extract the charge cooling effects of fuels, injected during the compression stroke, from the cylinder pressure measurements
- Capture the effects of ethanol concentration on the evolution of cylinder pressure using a multiple component fuel vaporization model
- Introduce single and split injection to enable the computation of *residue* feature

Status

✓ Ethanol detection concept via PS-C during compression stroke

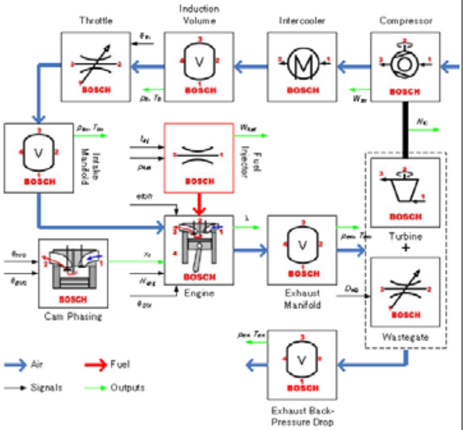
✓ Correlation of fuel vaporization model with experimental data at specific operation conditions for E0, E55, and E85

✓ Correlation of the *residue* feature, extracted from measured cylinder pressures, with measured ethanol content

Next Steps

- Online adaptation algorithm to achieve fast and accurate estimation of the ethanol content
- Robustness improvement of the proposed ethanol detection strategy by integrating the information from other existing sensors
- Vehicle-level implementation of the concept

Engine Controls



Approach

- In-cylinder pressure sensor based closed-loop combustion control via spark timing
- Optimized EGR control via VVT during part load transients
- Coordination of electronic throttle, turbo charger waste-gate, and VVT system in boosted regions

Status

✓ The concept lay out for model-based close-loop control of combustion event via in-cylinder pressure sensing

✓ A control-oriented mean-value engine model

✓ Vehicle-level development and calibration of the base ECU with in-cylinder pressure sensing

Next Steps

- Multi-variable feedback controller for combustion and sub-system controls
- Parameterization of the engine model with data from the optimized engine
- Vehicle-level investigation of transmission shift strategy based on ethanol content in fuel

Advanced FFV – Publications and Patents

- "Parameter Optimization of a Turbo Charged Direct Injection Flex Fuel SI Engine" Christie, M., Fortino, N., Yilmaz, H. (2009). *SAE Technical Paper* 2009-01-0238
- "Parameterization and Simulation for a Turbocharged Spark Ignition Direct Injection Engine with Variable Valve Timing" Jiang, L., Vanier, J., Yilmaz, H., Stefanopoulou, A. (2009). *SAE Technical Paper* 2009-01-0680
- "Ethanol Detection in Flex-Fuel Direct Injection Engines using in-Cylinder Pressure Measurements" Oliverio, N., Jiang, L., Yilmaz, H., Stefanopoulou, A. (2009). *SAE Technical Paper* 2009-01-0657
- "Modeling the Effects of Fuel Ethanol Concentration on Cylinder Pressure Evolution in Direct Injection Flex-Fuel Engines" Oliverio, N., Jiang, L., Yilmaz, H., Stefanopoulou, A. (2009). In Proceedings of *2009 American Control Conference*, St. Louis, Missouri, USA, June 10-12, 2009
- Patent Application on *Fuel Composition Recognition and Adaptation System*

Questions?

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