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A Mixed Mode HCCI/DI Engine Based on a Novel Heavy Fuel Atomizer

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Outline

1. Background
2. Mixed-mode HCCI/DI concept
3. Enabling Technologies
4. Control System Development
5. Future Work

1.Background

Keys to successful HCCI (with emphasis on heavy fuels)

- Highly mixed, homogeneous fuel/air/residuals charge preparation
- Tight control of intake charge composition and temperature
- Control over temperature/pressure history
- Cold start enabler
- Possibly after-treatment (and exhaust temperature conditioning)

2. Mixed-mode HCCI/DI Concept

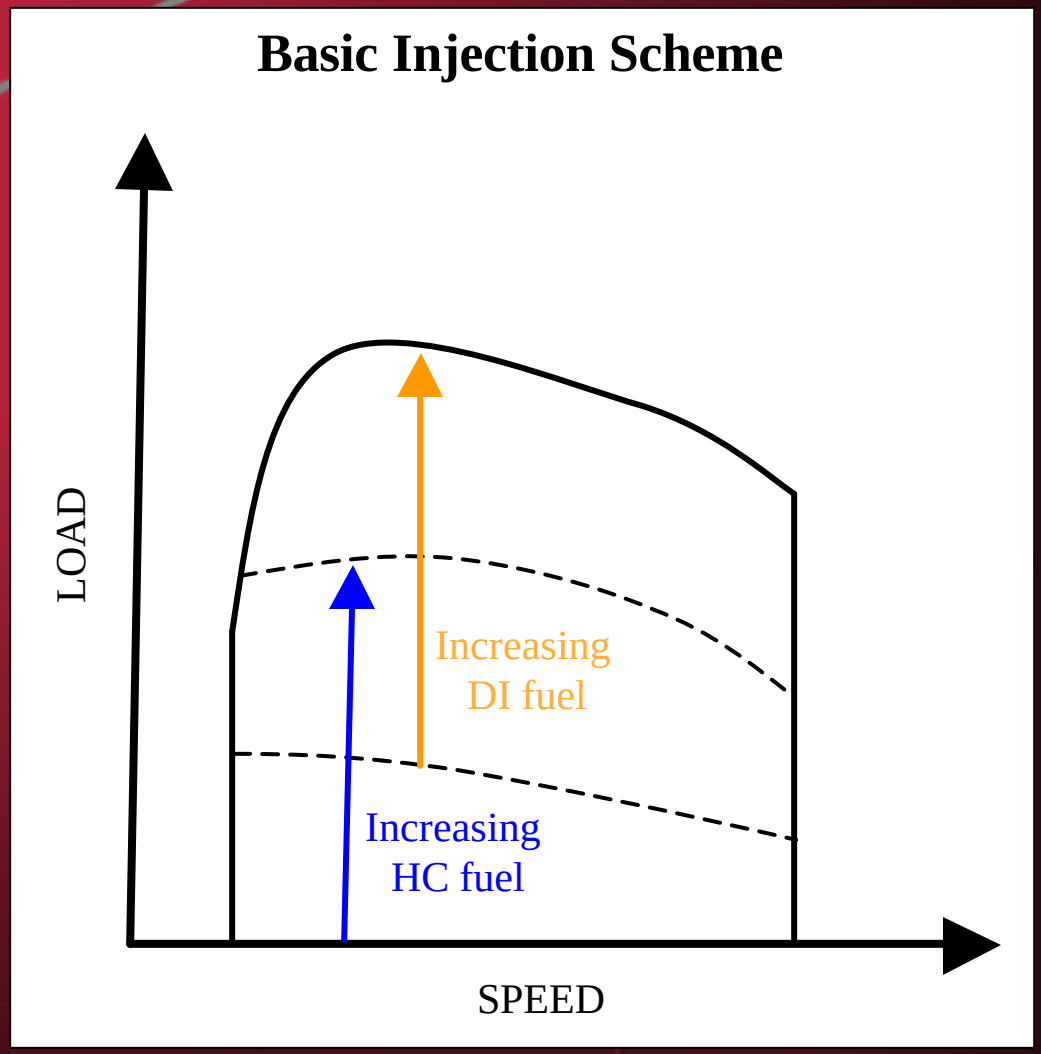
- Single fuel system: Diesel
- Two injection systems
  - Port/manifold injection – low pressure atomizer system
  - Direct injection - high-pressure injection system
- Atomizer system delivers fuel as a pre-mixed lean homogeneous mixture in the cylinder.
- Homogeneous charge ignites due to compression, or alternatively due to triggering from direct injection pulse
  - Allows more control over HCCI SOC

2. Mixed-mode HCCI/DI Concept

- Small droplet size (< 1μm mean diameter) allows rapid evaporation during compression stroke, removing the need for intake air heating (leading to higher CR).
- EGR and valve actuation control (based on models of combustion delay and reaction rates) permits SOC control.
- Direct injection supplements the reaction with additional fuel as a function of load for high-torque output.

Engine Operation

- Low load
  - Main torque from homogeneous charge (HC) fuel
  - Direct Injection (DI) mainly for ignition
- Mid load
  - Increasing HC fuel
  - Increasing DI fuel
- High load
  - Max HC fuel
  - Increasing DI to full load



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3. Enabling Technologies

Fuel Atomizer

- Low-Pressure diesel fuel atomizer
- < 1 micron droplet size
- Non-wetting
  - Forms suspension in still air
- Cold weather tested
- Reliability, manufacturability, and cost hold promise for use in automotive industry

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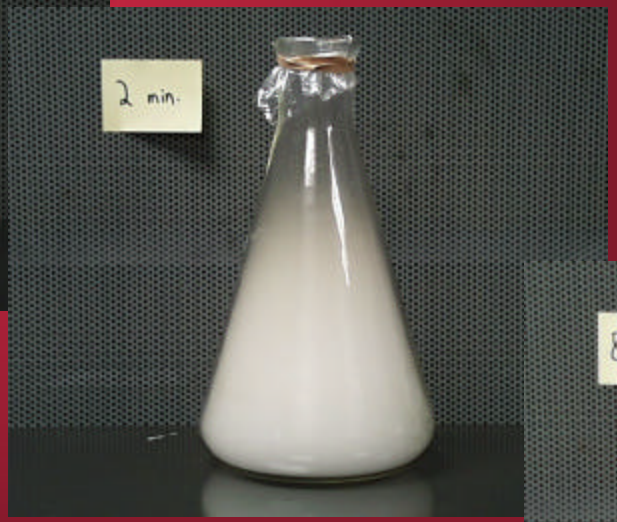
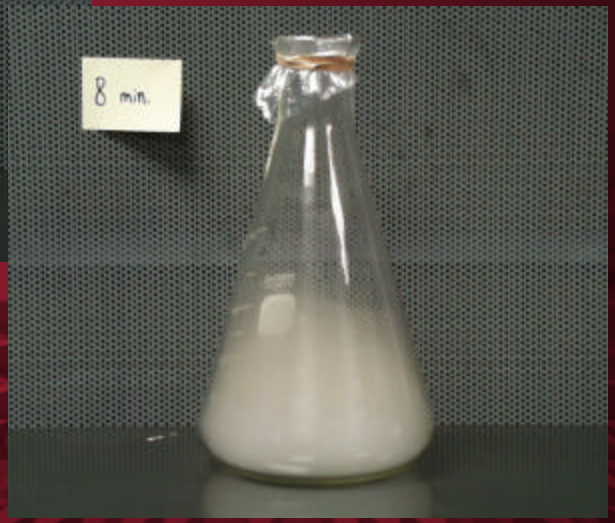
Atomization Quality

T = 0 min.



T = 2 min.



T = 8 min.

2 mL of diesel in a 2 L flask at room temperature

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Combustion Quality

Lean, pre-mixed diesel flame, 10 kW

Burner face area: 2”x2”

NO_X < 30 ppm

Flexible Valve Actuation

Fully flexible valve actuation allows for precise control on effective compression ratio (temperature/pressure history), as well as internal residual gases. It also allows for control of in-cylinder flow field, mixing, heat transfer, charge stratification (if desired). Flexible valve actuation also need to be tightly included in model-based control.

Flow field control

Both geometry (port/head) and actuation (valve lift laws, possibly other actuators) have a profound effect on in-cylinder flow fields, mixing and heat transfer. These effects are more critical for HCCI than for conventional SI and CI mode of operation.

System Control

Model-based control, possibly with a new actuator/sensor set, is a must for precise delivery of intake charge with tight tolerance on composition (air/fuel/residuals), temperature and pressure (both at steady state and during speed/load transients) .

Other Benefits of Proposed Approach towards HCCI

- The same atomizer used in a burner configuration can provide the proper thermo-chemical management of after-treatment systems independent of engine operation.

Current State of Progress

- Atomization device developed to point of being a reliable, controllable, prototype device
- Direct-injection, diesel engine research cells functional
- Experience with diesel engine control, modeling, and experimentation
- Seeking industrial or government partner to proceed in the development of the concept

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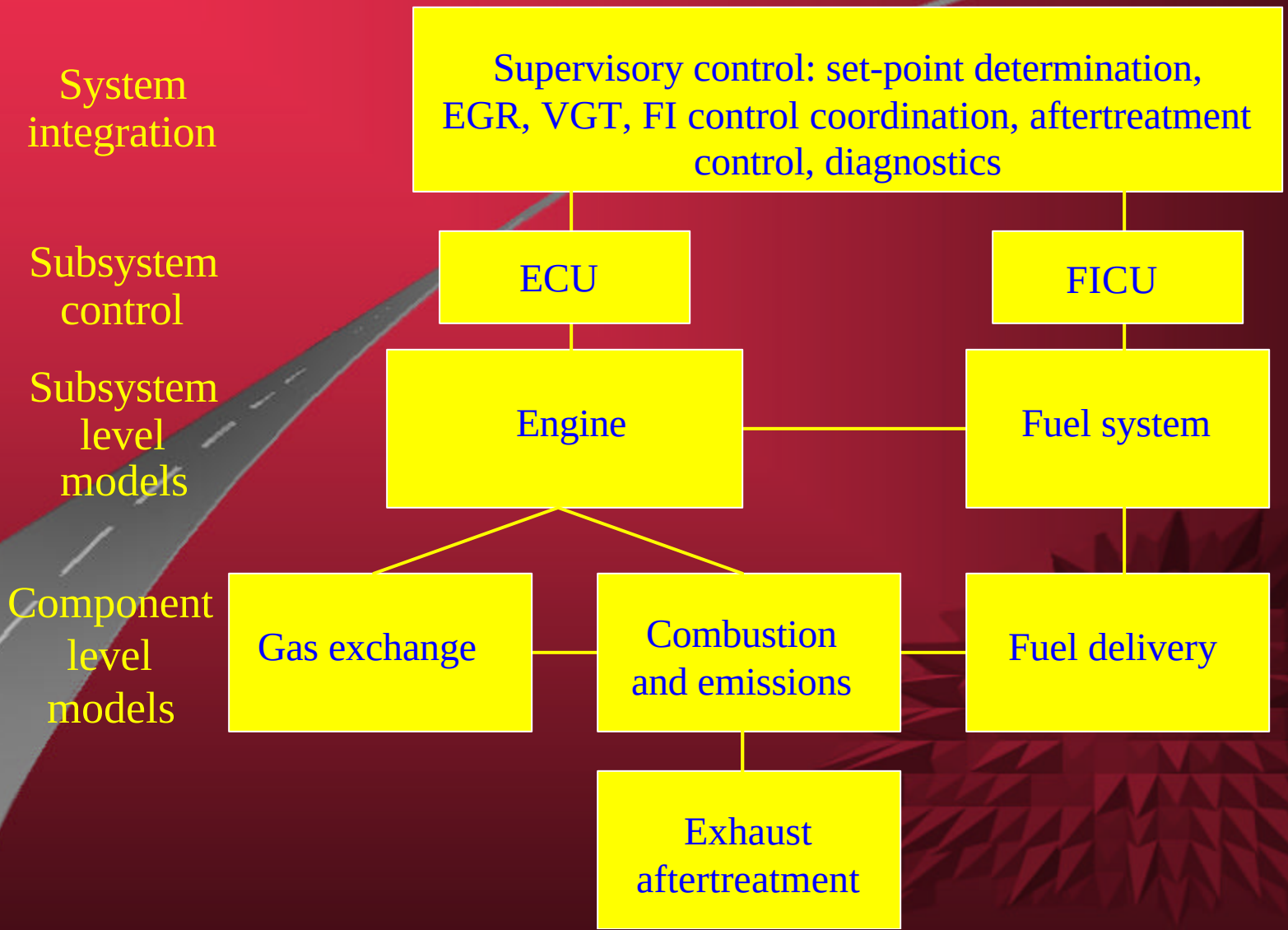
4. Control System Development

Control System Development



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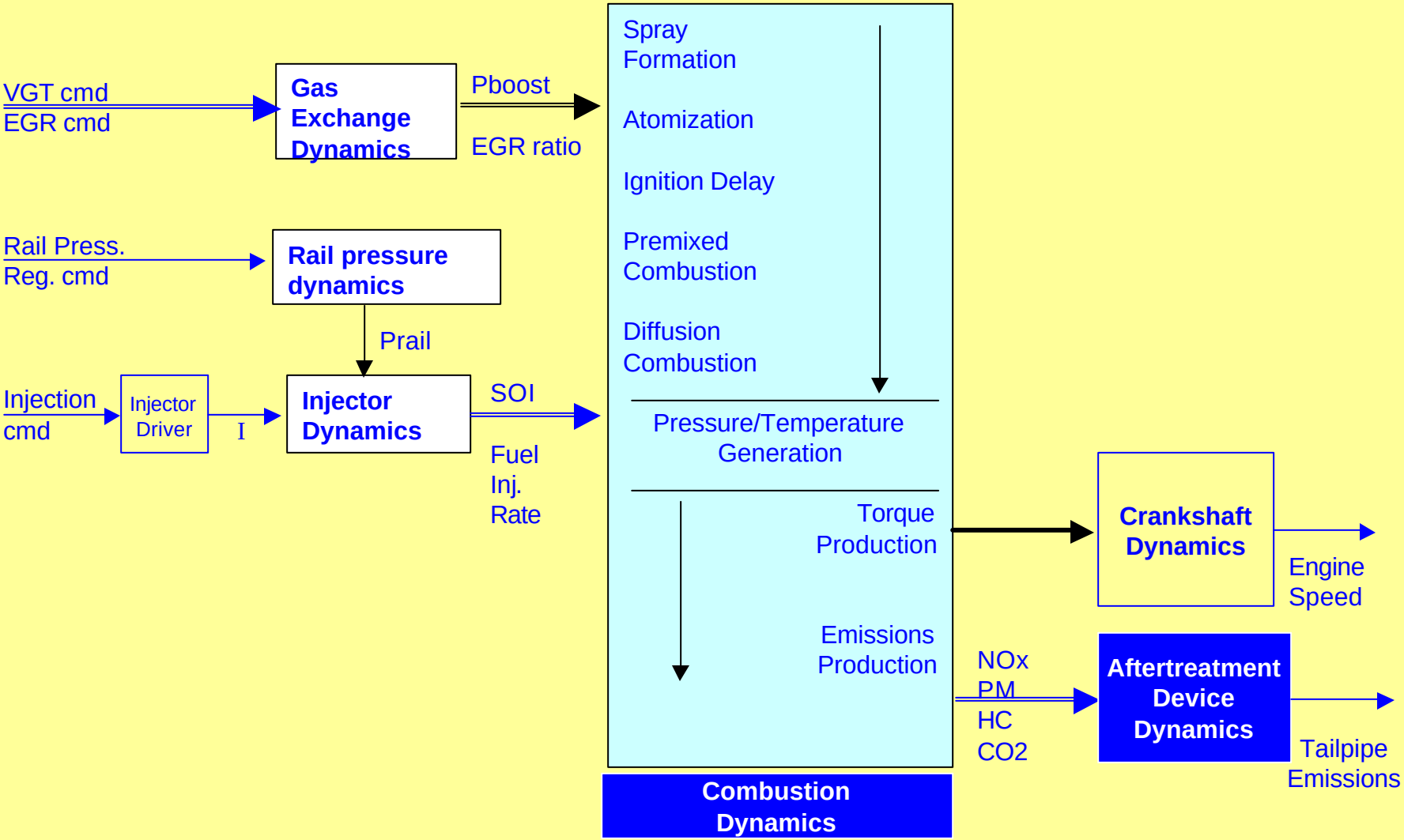
CIDI Engine System Diagram



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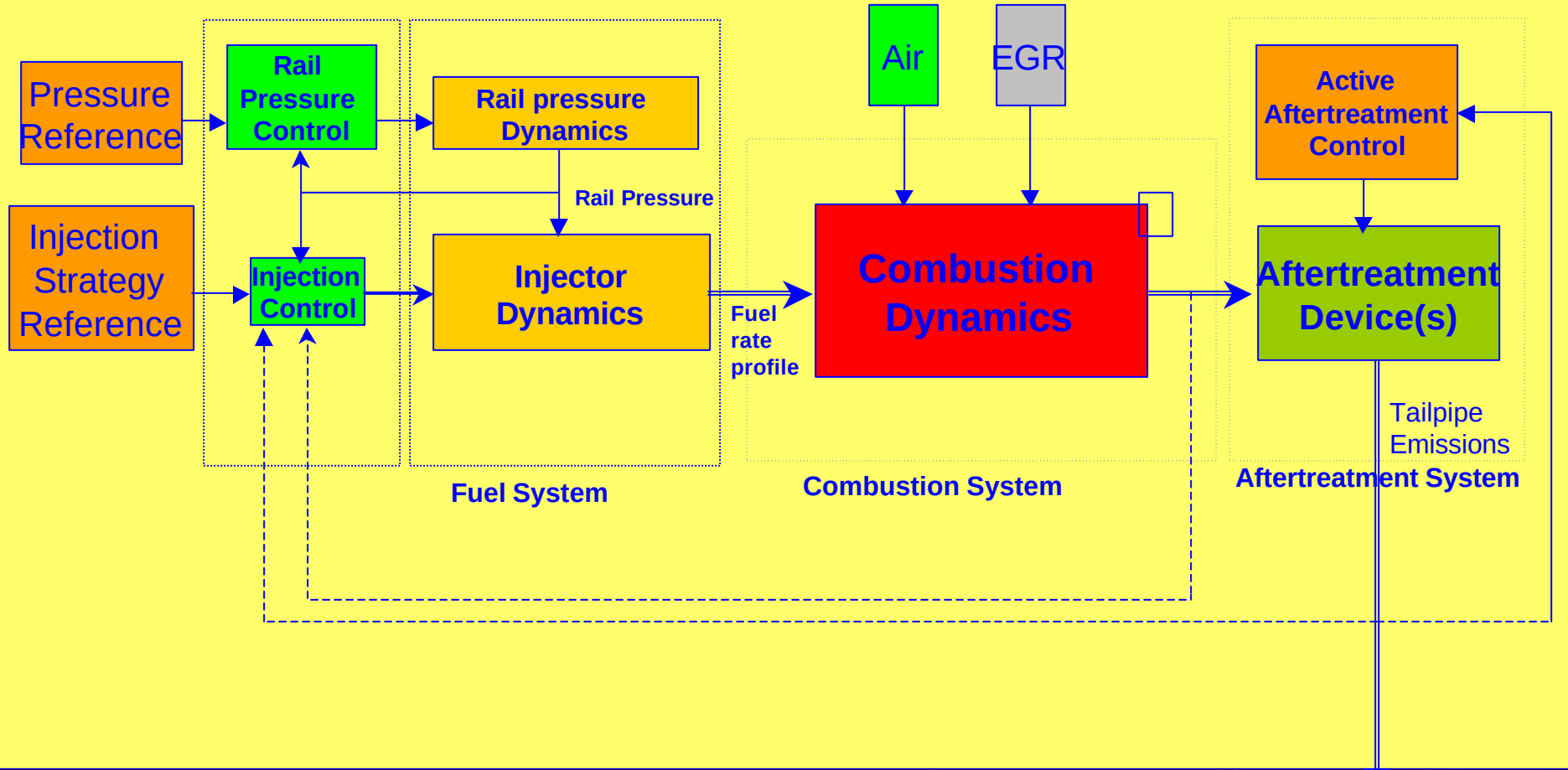
CIDI Engine Closed Loop Combustion and Emissions Control



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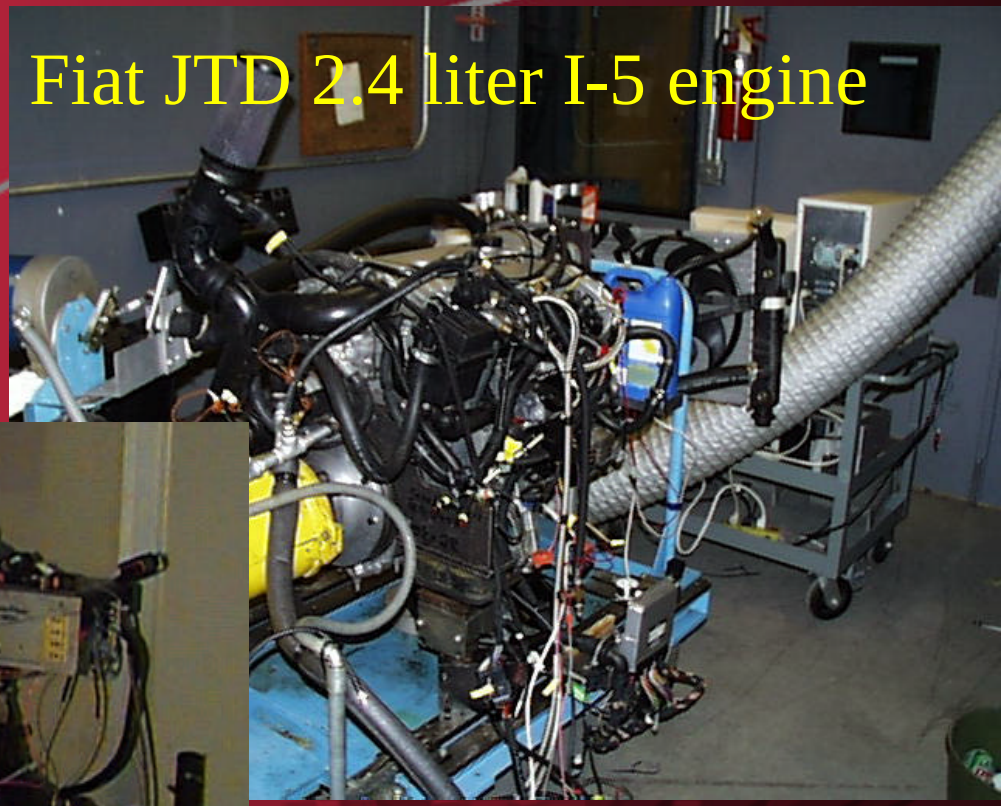
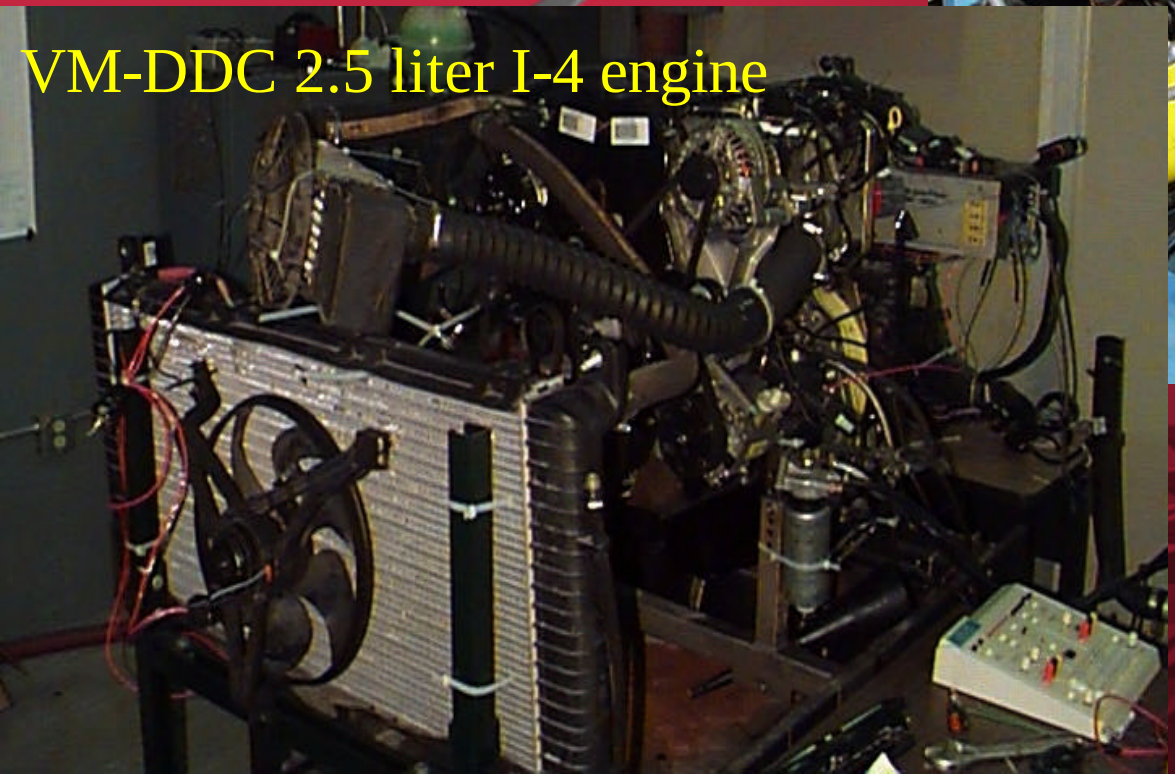
Experimental facilities

Fiat JTD 2.4 liter I-5 engine



VM-DDC 2.5 liter I-4 engine



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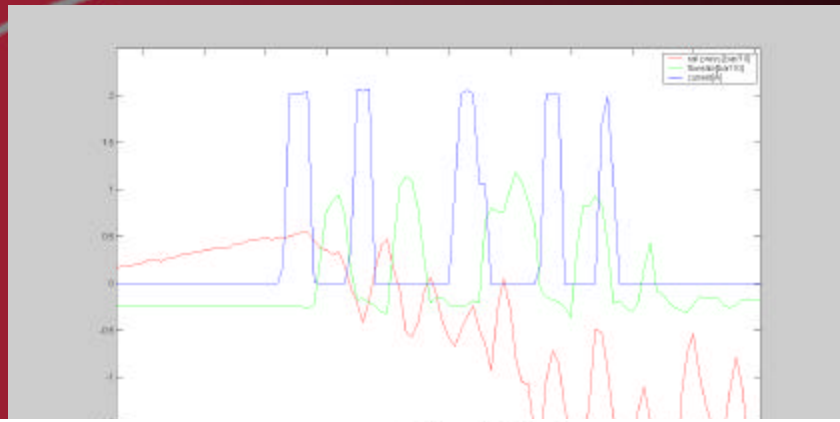
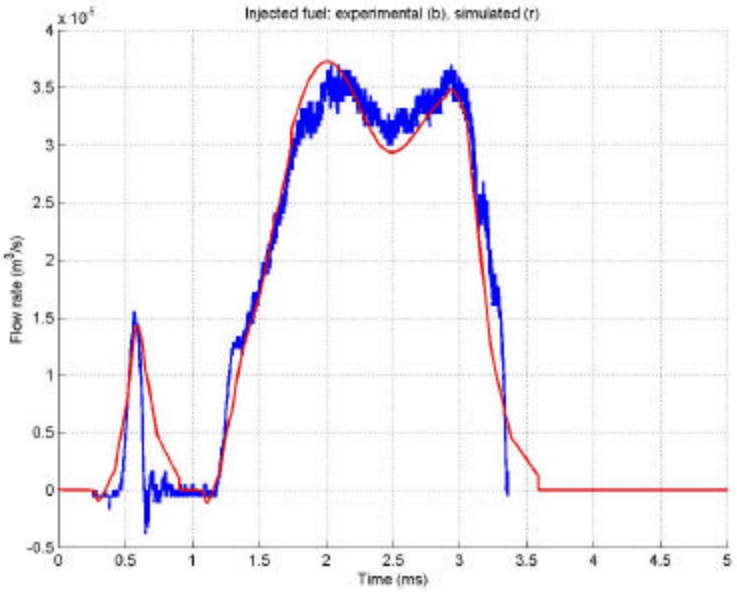
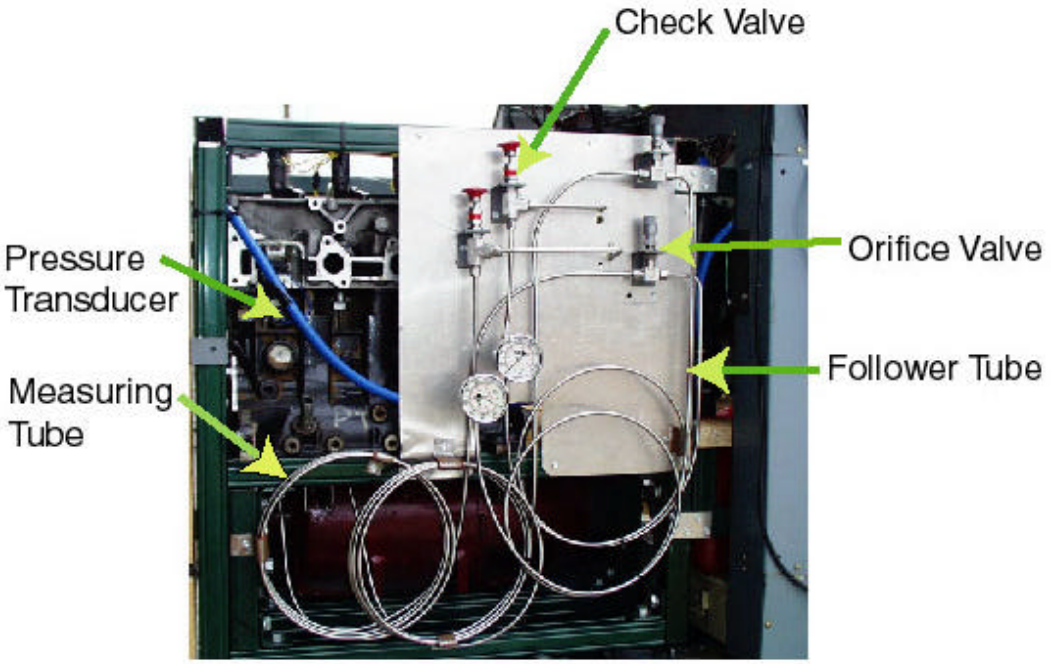
Modeling andControl of Common Rail-CIDI injection systems

- Fuel injection rig with
  - Bosch tube flow rate measurement
  - Bosch common rail injection system
- Flexible injection command capability
  - STMicroelectronics analog driver
  - STMicroelectronics digital driver
  - Dspace/ETAS







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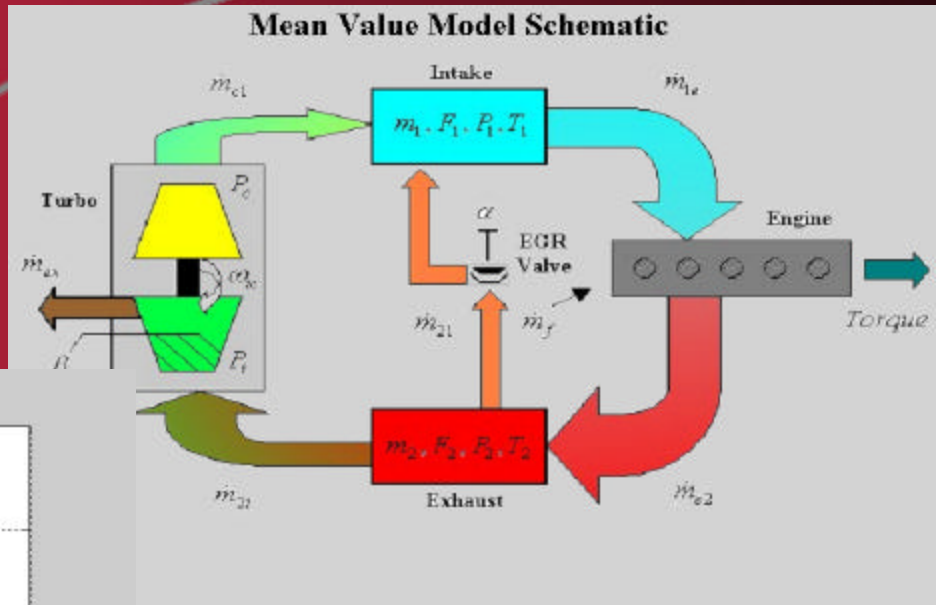
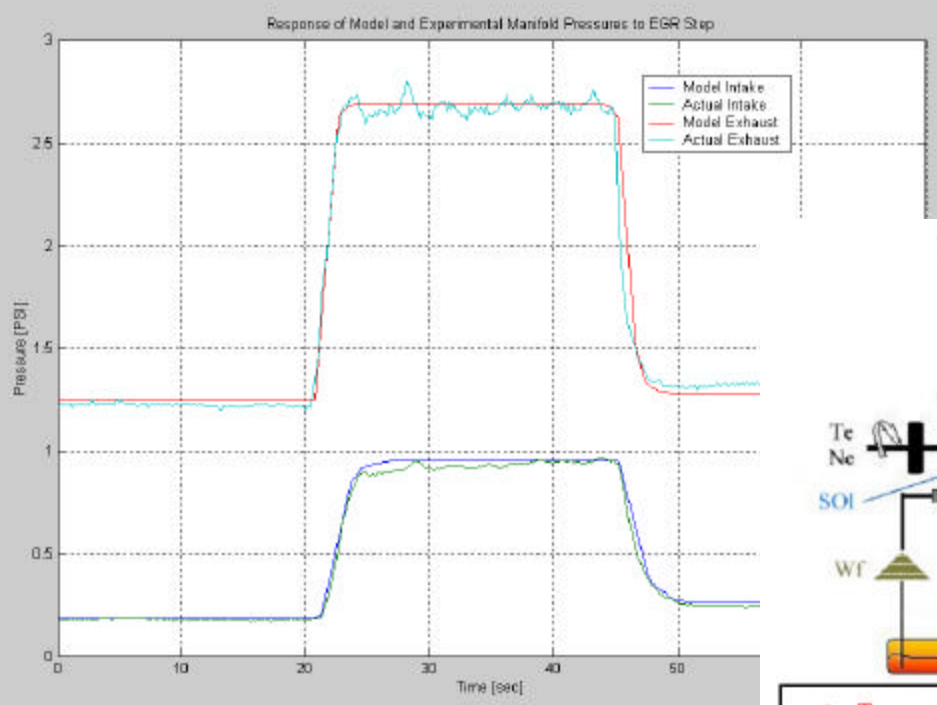
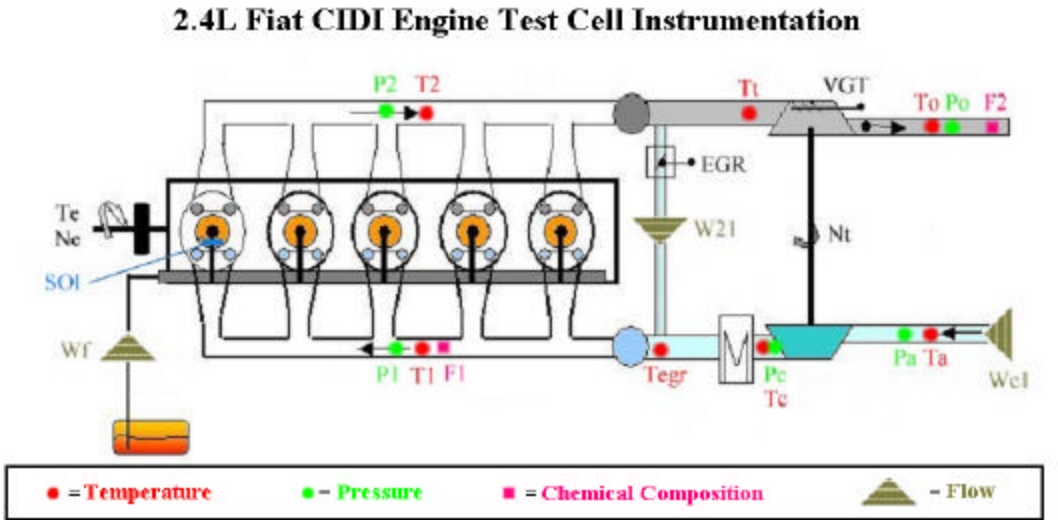
Modeling and Experimental Validation of CIDI Engines

- Mean value engine model
  - EGR-VGT influence on intake air flow and characteristics
  - Useful for control development
- Test Cell Matching and Validation
  - Model matched to a Fiat 2.4L engine
  - Experimentally validated







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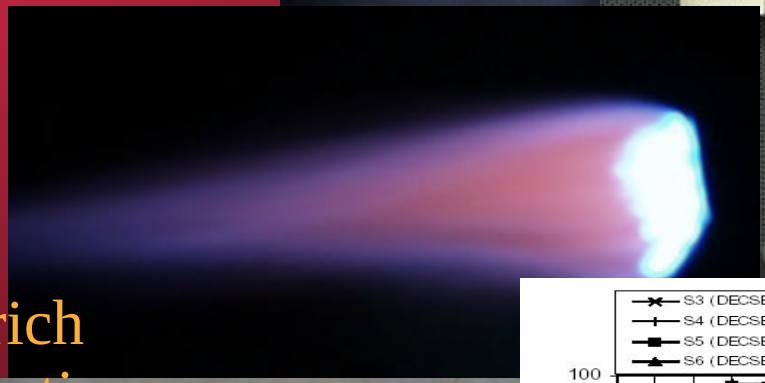
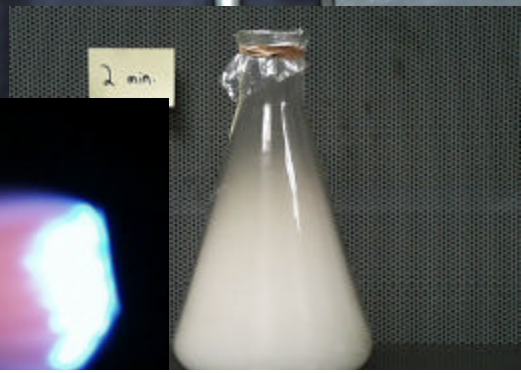
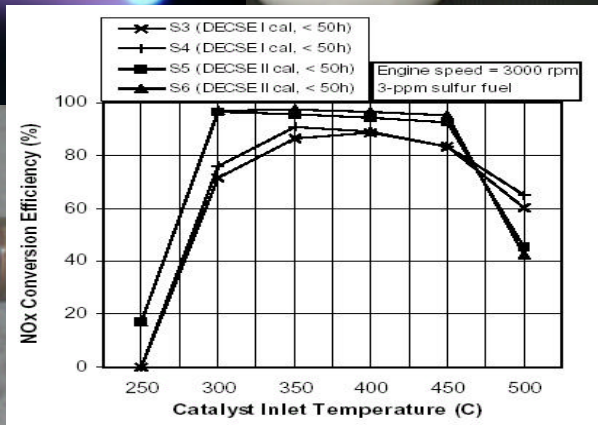
Diesel NOx AfterTreatment Systems

- Remove the burden of catalyst management from the engine by addition of a novel “actuator”.
  - Deliver heat on demand for rapid catalyst light-off
  - Provide HC’s for NOx regeneration
  - Provide CO for NOx regeneration
  - Provide prolonged hot, rich gasses for sulfur regeneration







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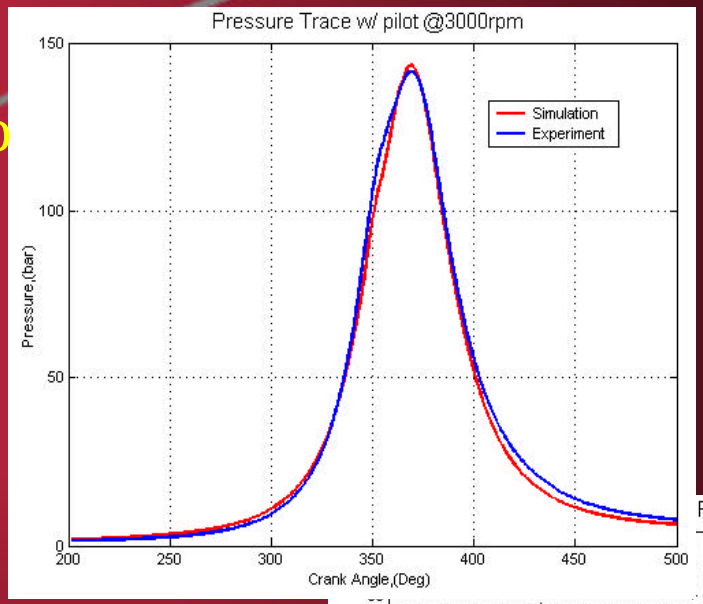
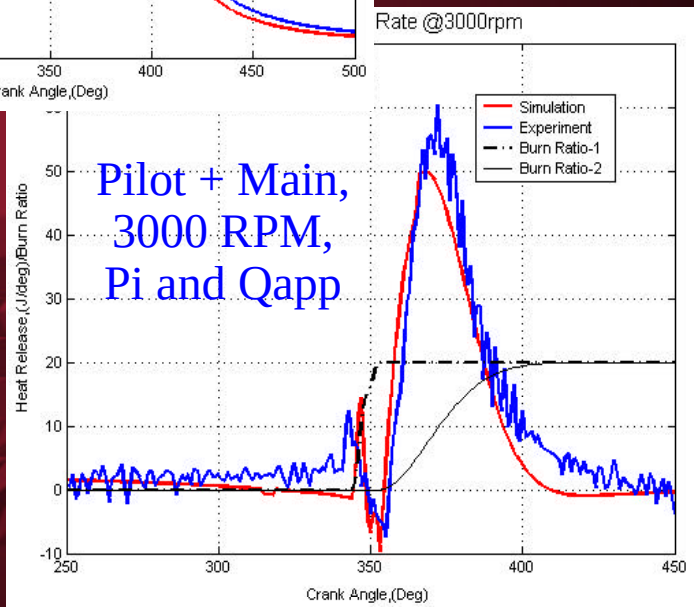
Crank-angle resolved modeling of CIDI engines with multiple injections

- Crank-angle resolved model of combustion and emissions in CIDI engine links effects of multiple fuel injection pulses to in-cylinder characteristics.
- Heat release and emission model validation in engine test cell with multi-cylinder CIDI engine capable of multiple injection
- Validated multi-cylinder CIDI simulator for:
  - Fueling law optimization
  - Control system development (injection, VGT, EGR)





5. Future Work

- Further development of atomizer to fit application
  - Packaging and control
  - Development of hardware and experimental setup to evaluate and calibrate the concept
  - Research engine already in place
- Implementation on a single cylinder research engine (partners?)
- Implementation on a multi-cylinder, direct injection engine.
- Extensive investigation of steady state engine characteristics with mixed mode HCCI
  - Torque production, emissions, fuel consumption
- Provided the above shows promise; investigation of transient control of the engine.