Late-Cycle Injection of Air / Oxygen-Enriched Air for Diesel Exhaust Emissions Control

presented by

Daniel Mather

University of Wisconsin ERC

DEER Workshop - San Diego, CA

August 24, 2000

Technical Partners

- Argonne National Laboratory
  - Doug Longman
  - Ramesh Poola
- Caterpillar Inc.
  - Ashok Chanda
  - Tom Vachon
- University of Wisconsin - Madison, Engine Research Center
  - Daniel Mather
  - David Foster

Program Sponsors

- Caterpillar, Inc. - CRADA Partner
- DOE / Office of Advanced Automotive Technologies
- DOE/Office of Heavy-Vehicle Technologies

Program Objectives

ALTER THE SOOT vs. NOx DIESEL ENGINE TRADEOFF

- Reduce the “Engine Out” particulates using the “In Cylinder” technique of late cycle auxiliary gas injection (AGI).
- Reduce the “Engine Out” NO_x by combining AGI with optimization of fuel injection parameters.
- Maintain or Improve the Fuel Efficiency.

Auxiliary Gas Injection for In-Cylinder Reduction of PM in Diesel Engines

The Concept

Injection of air or oxygen-enriched air directly into the combustion chamber during the diffusion phase of the combustion cycle

- provides turbulent mixing with jet momentum
- increases oxygen concentration in the surrounding gas
- increases soot oxidation reactions without increasing NO_x formation
- simultaneous reduction of NO_x & PM can be achieved
  - optimized fuel injection (retarded timing, pilot injection, etc)
  - used in combination with EGR

Technical Approach - CAT 3401E

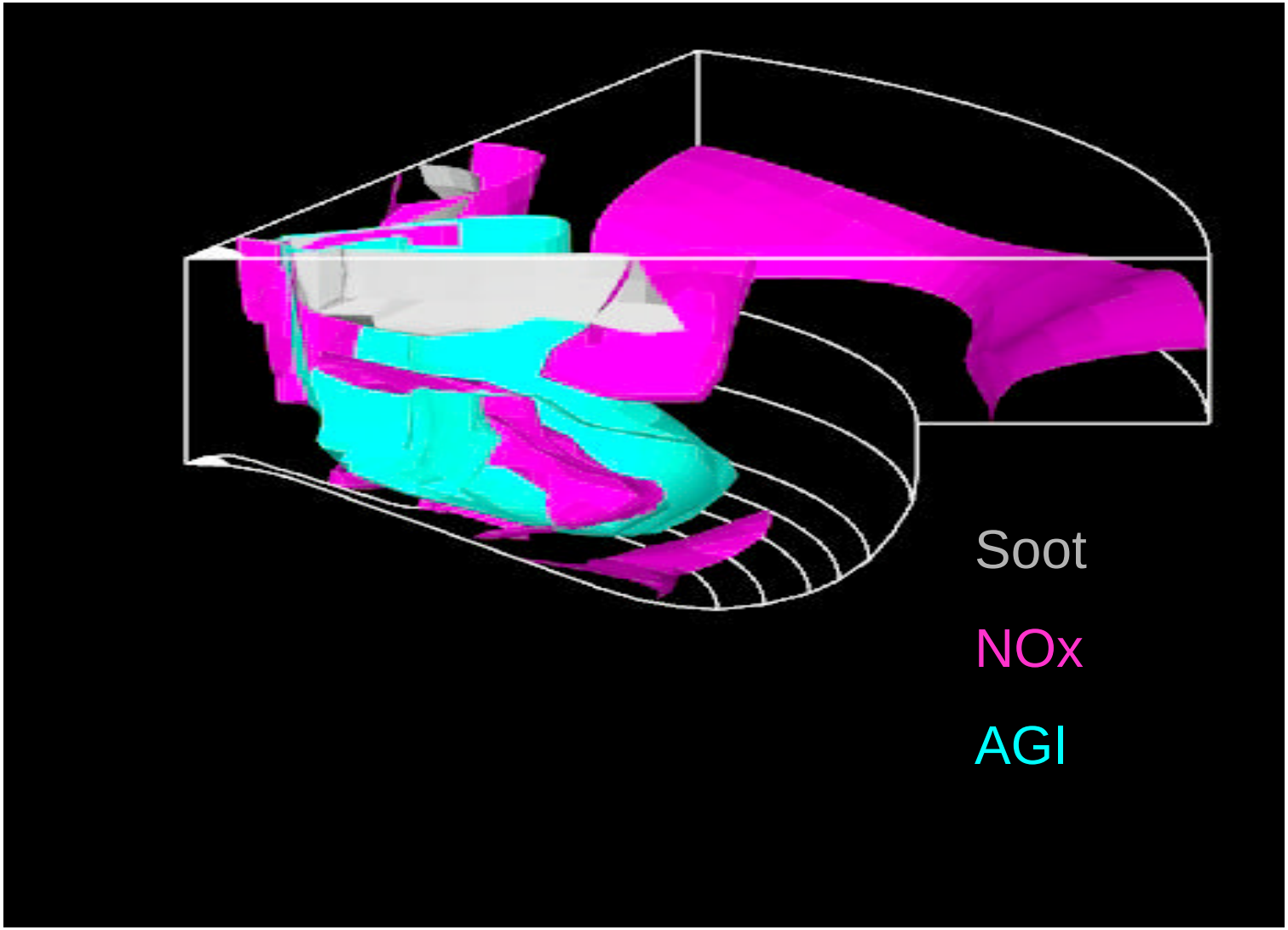
Modeling

- KIVA-3 simulations to optimize auxiliary gas injection and fuel injection parameters - collaboration with Engine Research Center/University of Wisconsin-Madison

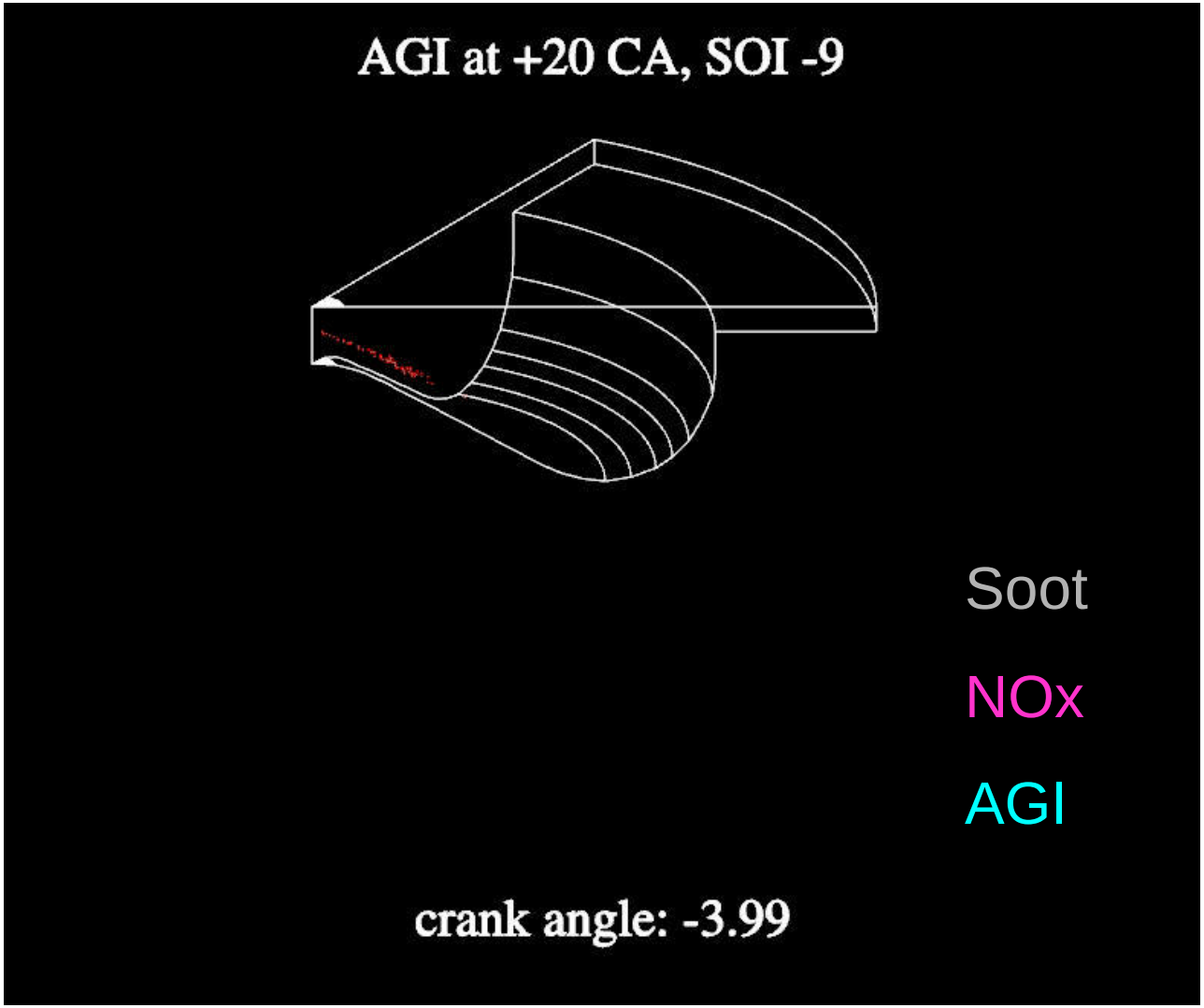
Experimental

- Setup single-cylinder diesel engine test stand at ANL and conduct late-cycle air or oxygen-enriched air injection experiments
- Verify the Model Results

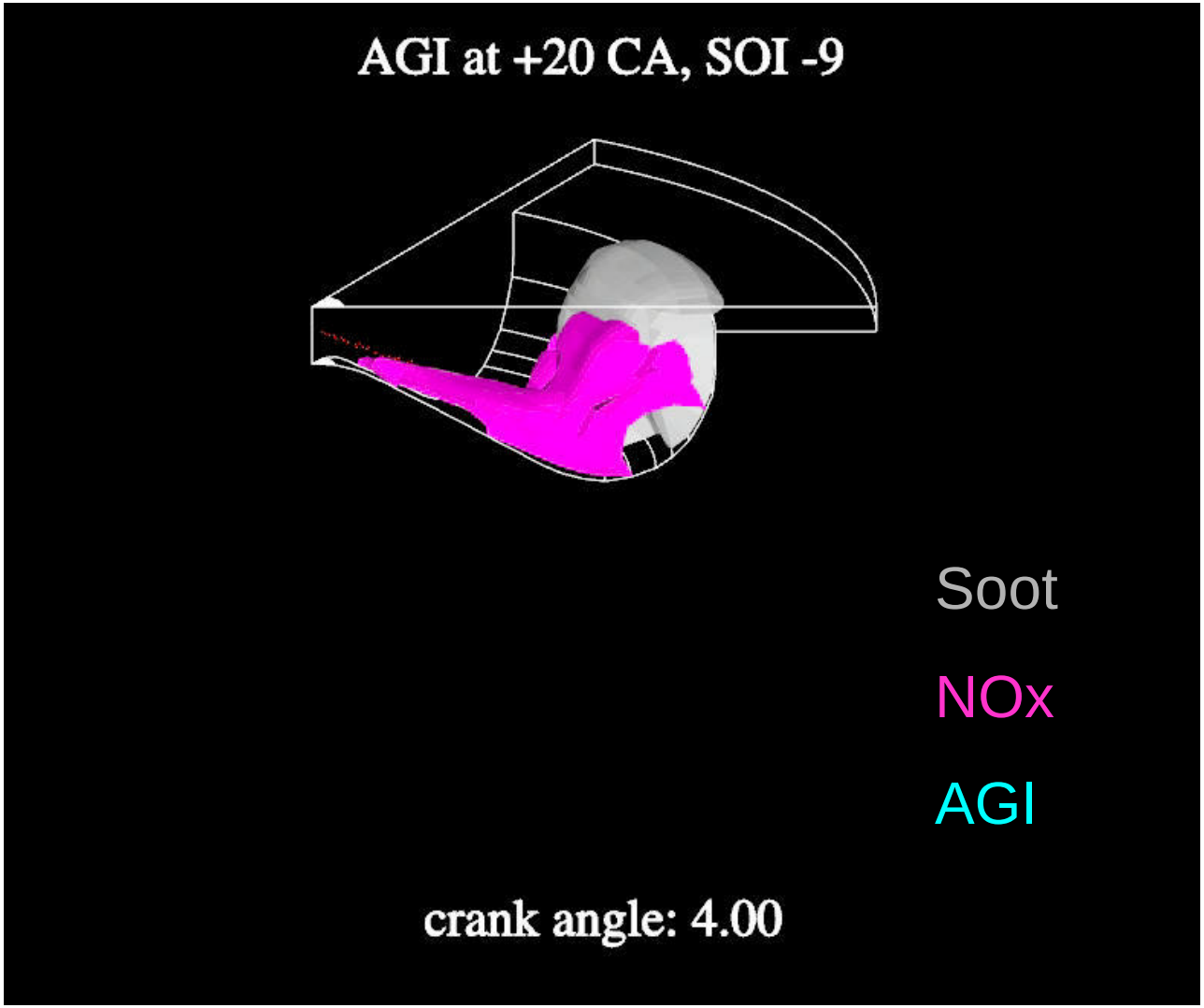
60 Degree Sector - Central Injector



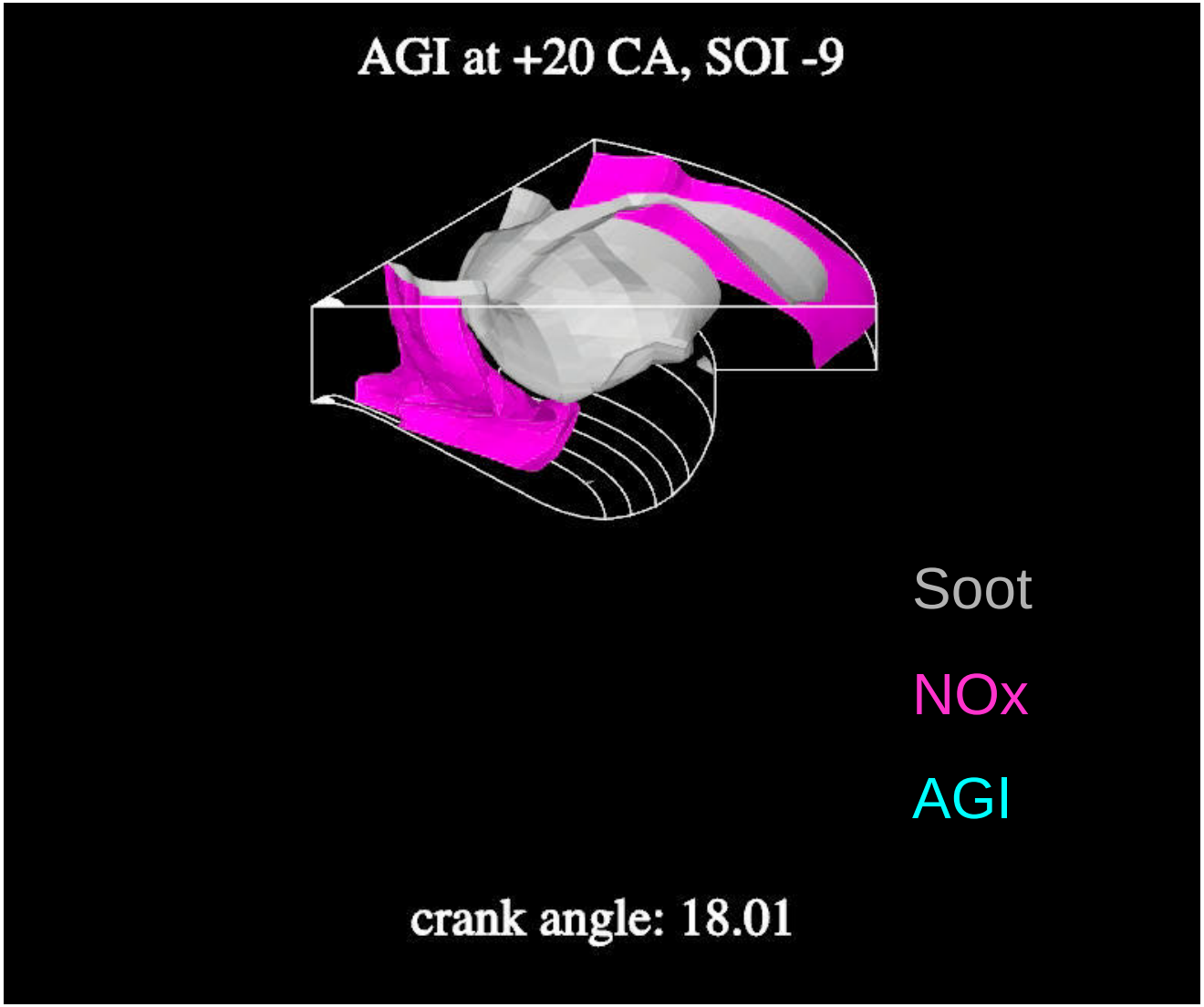
60 Degree Sector - Central Injector



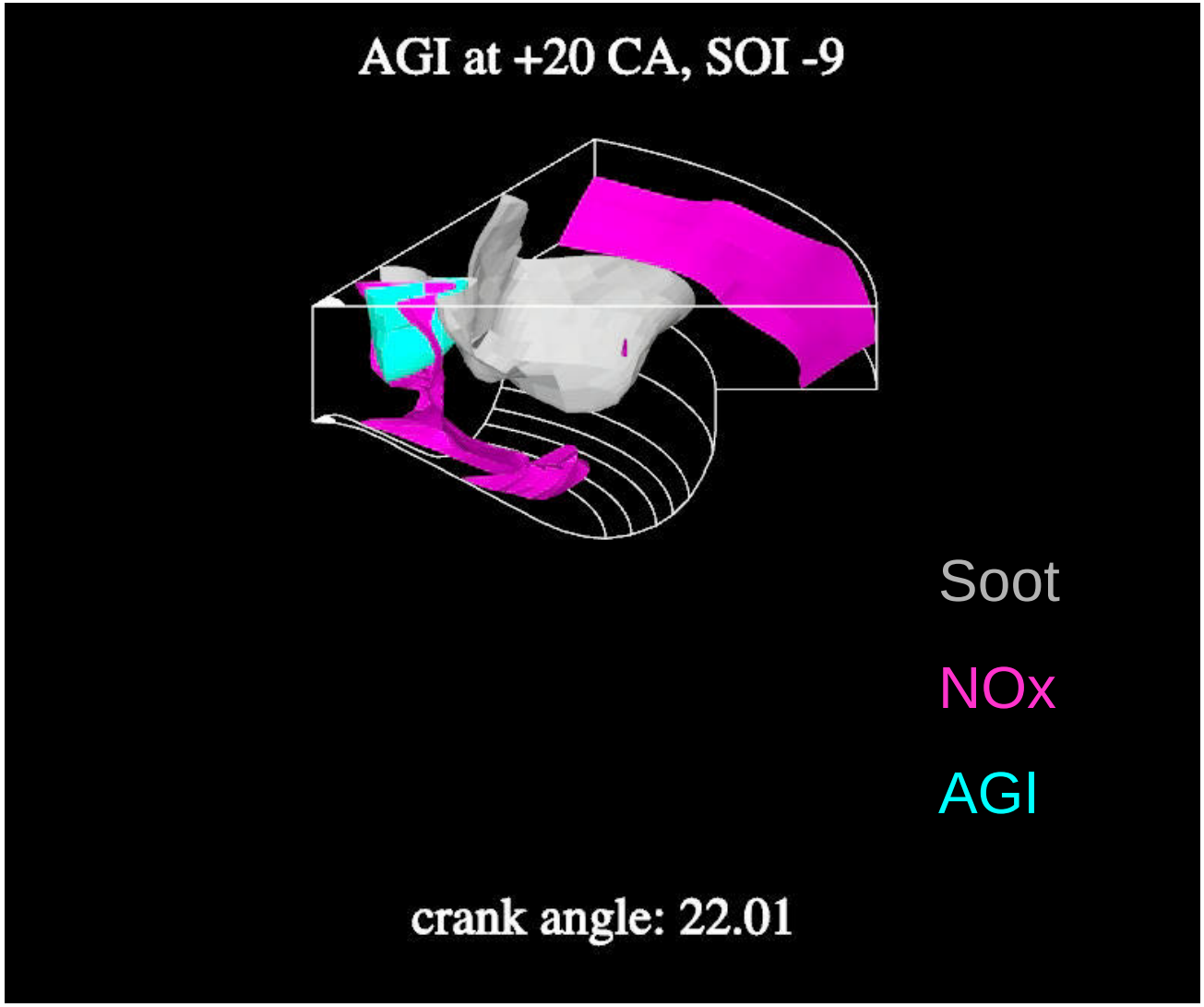
60 Degree Sector - Central Injector



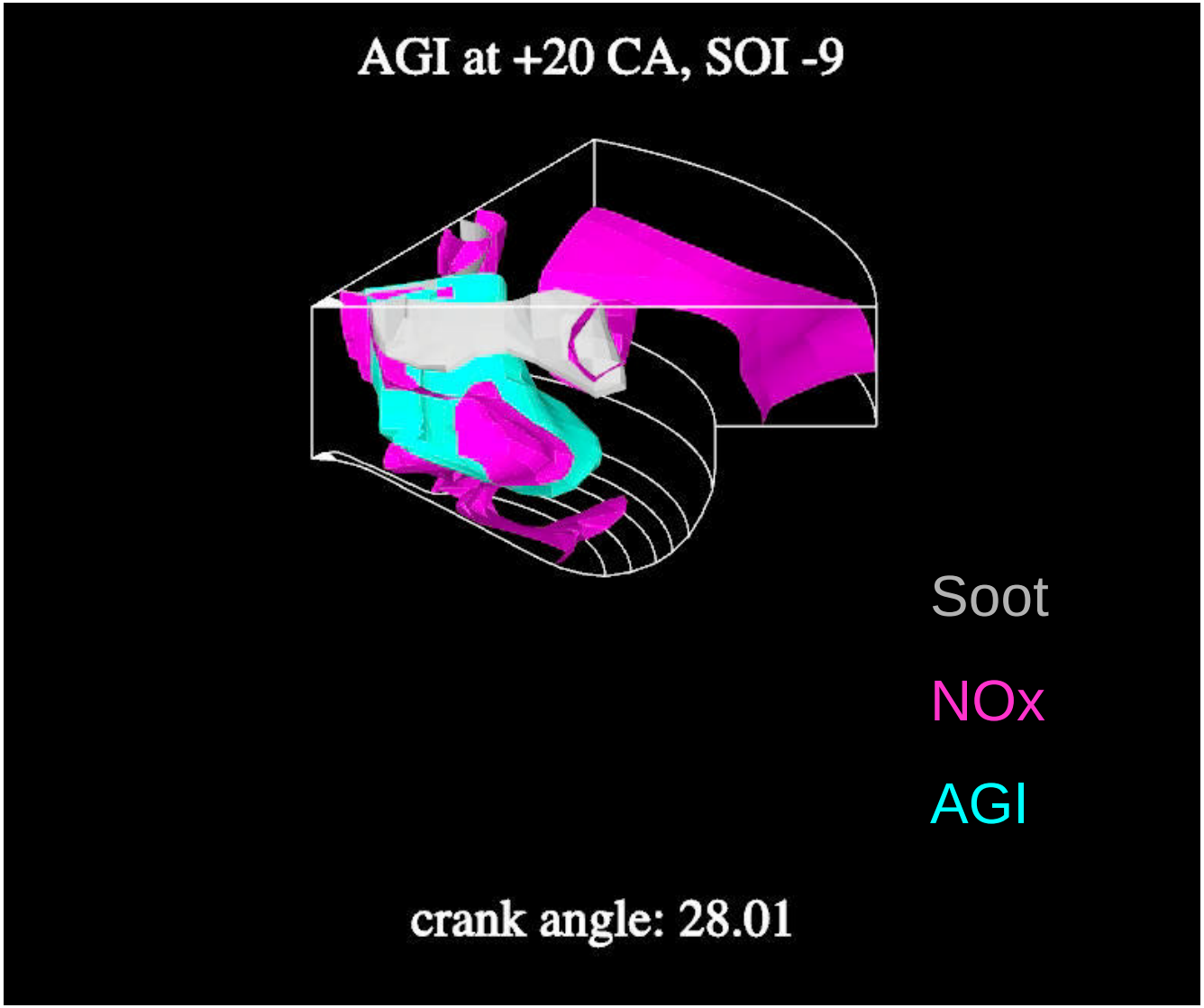
60 Degree Sector - Central Injector



60 Degree Sector - Central Injector

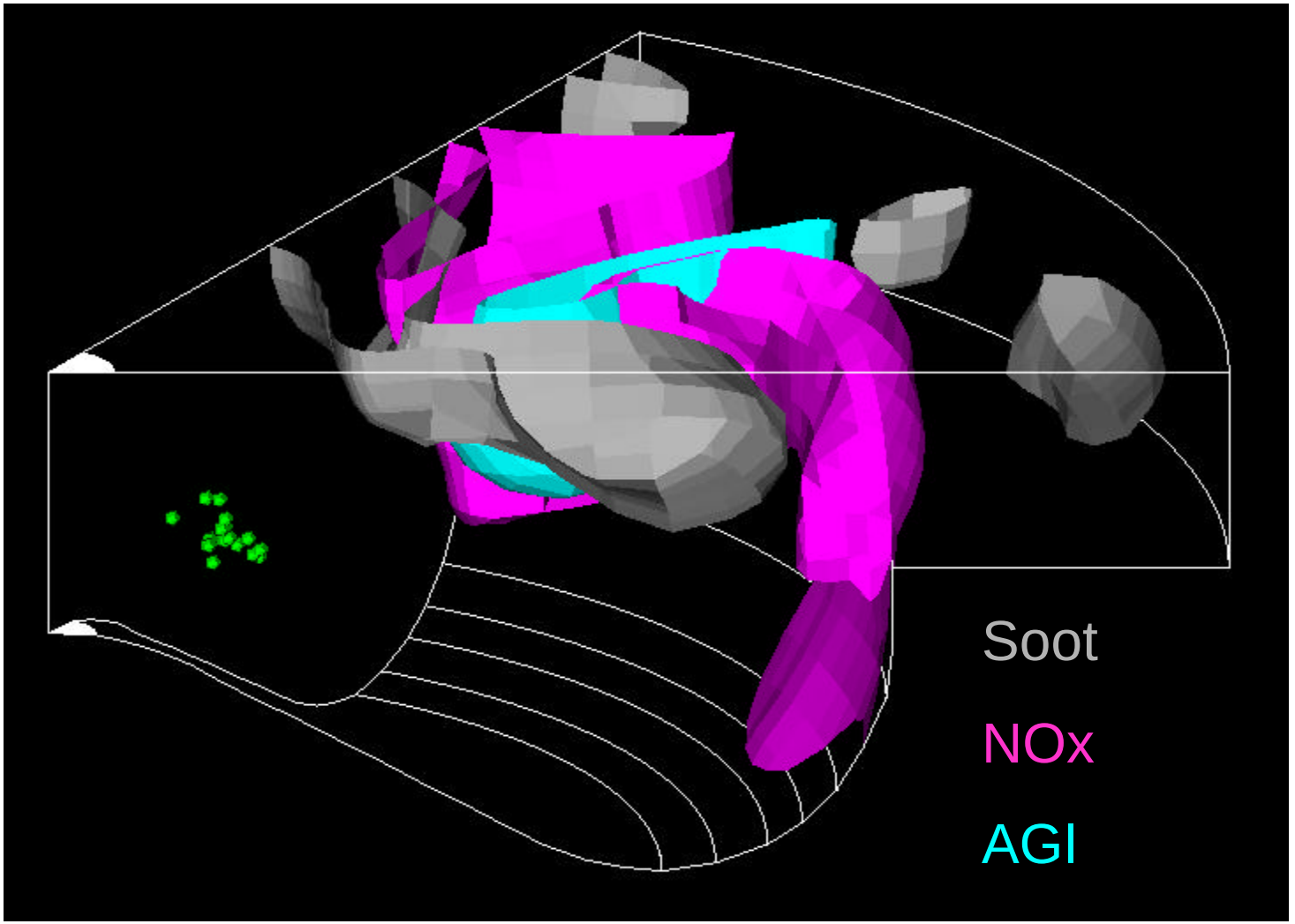


60 Degree Sector - Central Injector

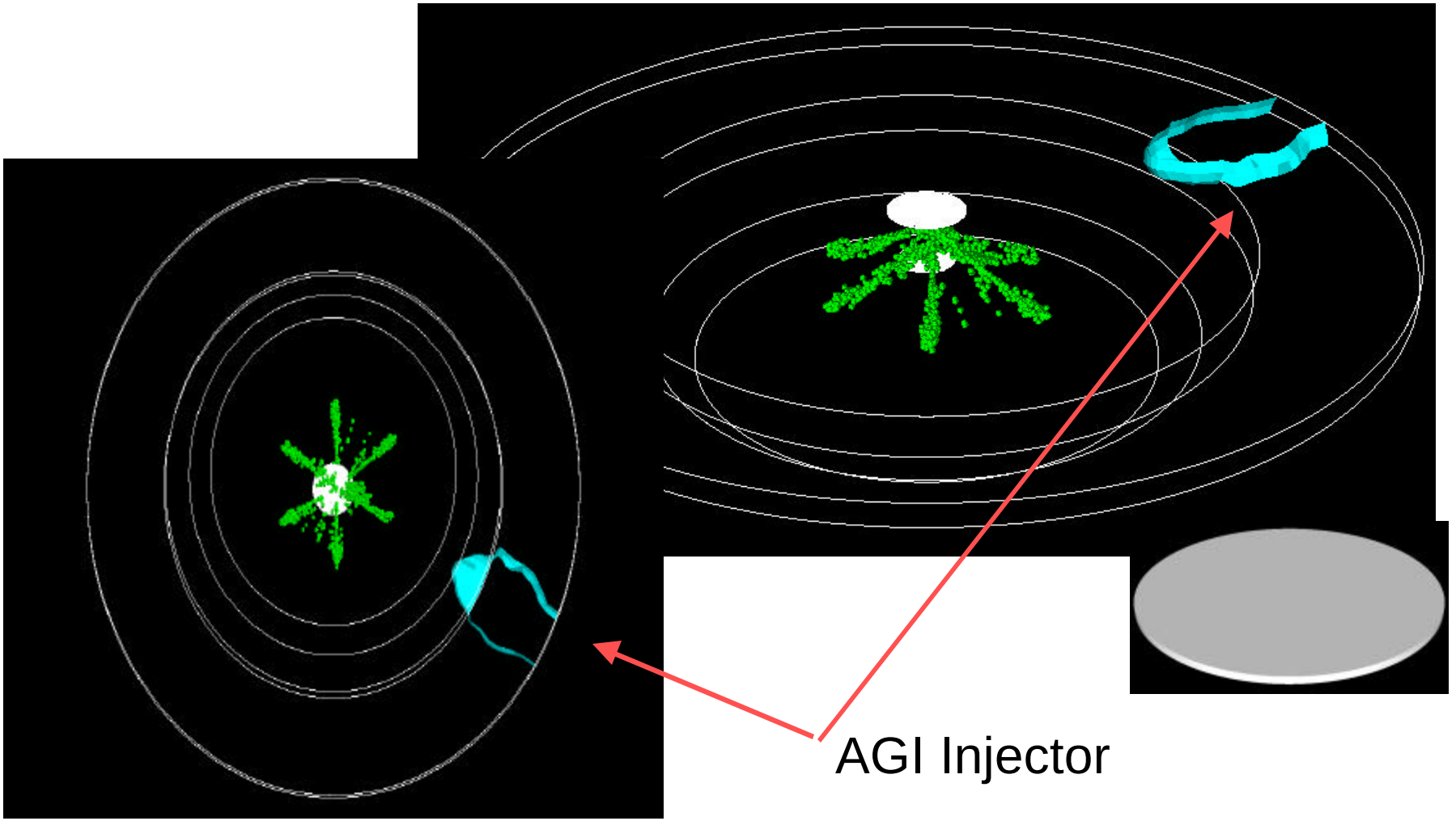


60 Degree Sector - Edge Injector

Edge Injection - 26 CA, BOGI 20 CA, SOI -7 CA



360 Degree Grid - Edge Injector



KIVA-3: Parameters that Influence the Effectiveness of Late-Cycle Air Injection

Objectives

Low air injection pressure & duration

Ambient air (no need for membrane)

Auxiliary air injection

Beginning of air injection

Duration of air injection

Injection pressure

Air temperature

Oxygen (%) level

Nozzle geometry
(dia and # of holes)

Injector orientation

Location of the injector
(with respect to fuel injector)

Combustion chamber geometry

In-cylinder charge conditions
(swirl, squish, and turbulence)

Engine speed/load

Fuel Injection

Beginning of injection

Duration of injection

Injection pressure

Injection rate & shape

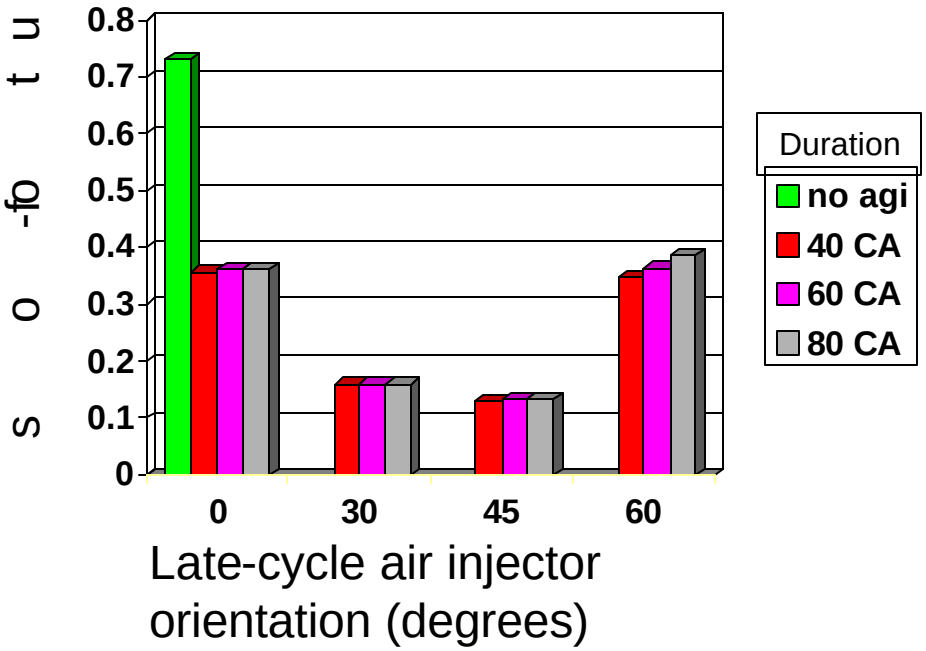
Intake air composition

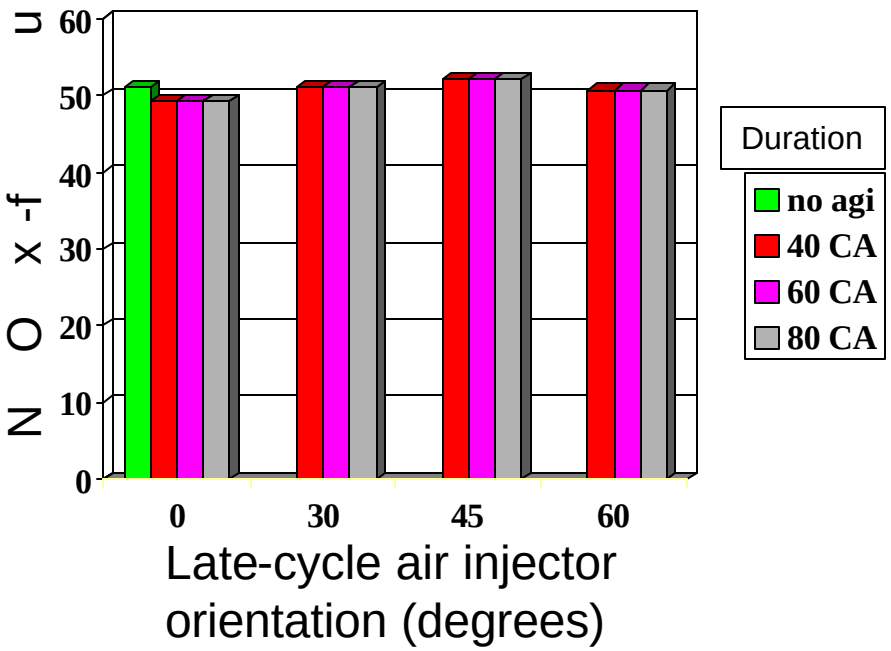
Oxygen purity
(***air***, O_2, or N_2-rich)

EGR?

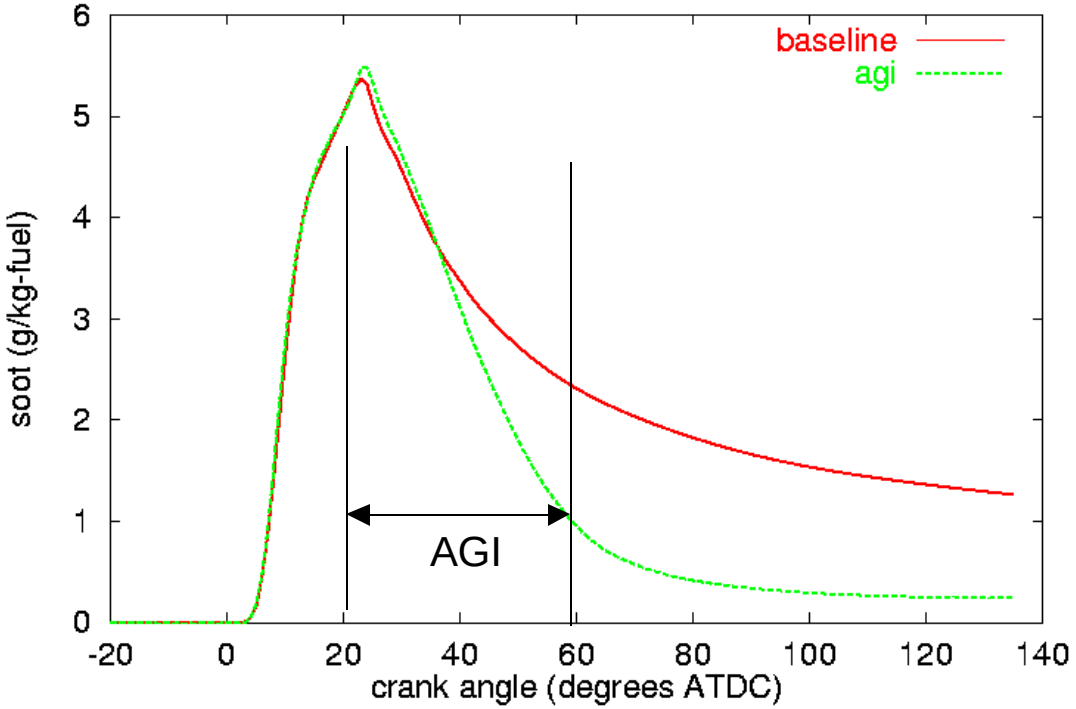
% Water

Late-cycle Air Injection Provides a Significant Mechanism for Affecting Soot Independently of NO_x





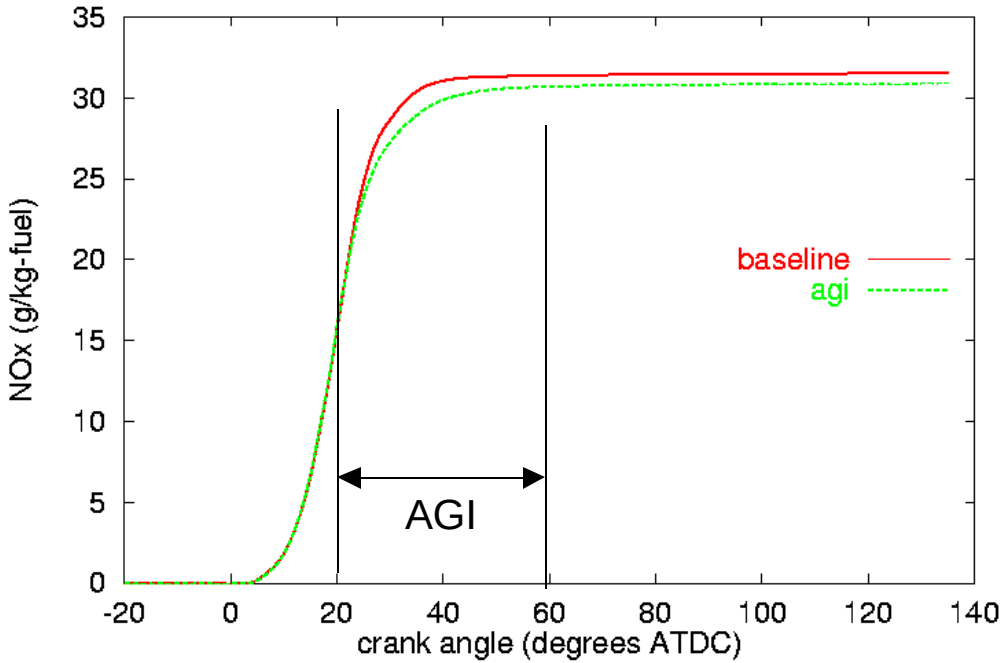
KIVA-3: Late-cycle Air Injection Provides a Significant Mechanism for Reducing Soot ……..



Run Conditions:

Beginning of oxygen-enriched air injection: 20° ATDC
Oxygen purity in the intake air: 25%
Start of fuel injection timing: Base timing (0° ATDC)
Test condition: Caterpillar Mode IV (1600 rpm, 43 hp)

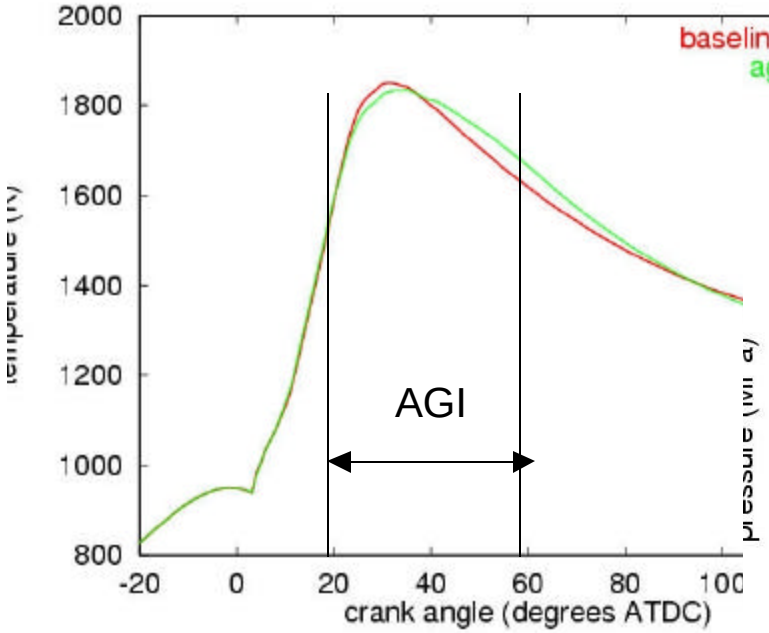
……..Independently of NO_x.

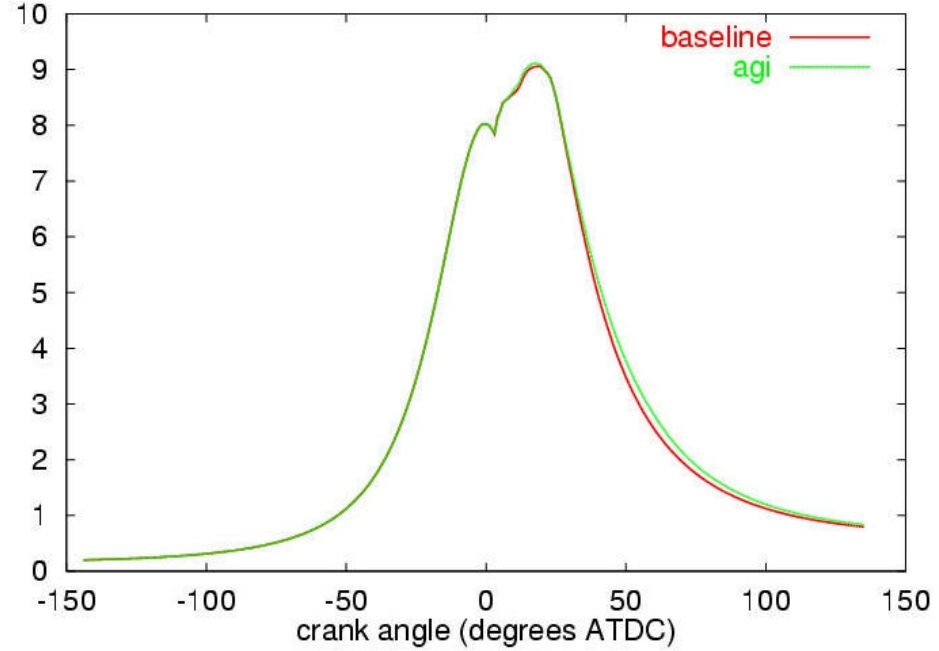


Run Conditions:

Beginning of oxygen-enriched air injection: 20° ATDC
Oxygen purity in the intake air: 25%
Start of fuel injection timing: Base timing (0° ATDC)
Test condition: Caterpillar Mode IV (1600 rpm, 43 hp)

……..During the Temperature Window …

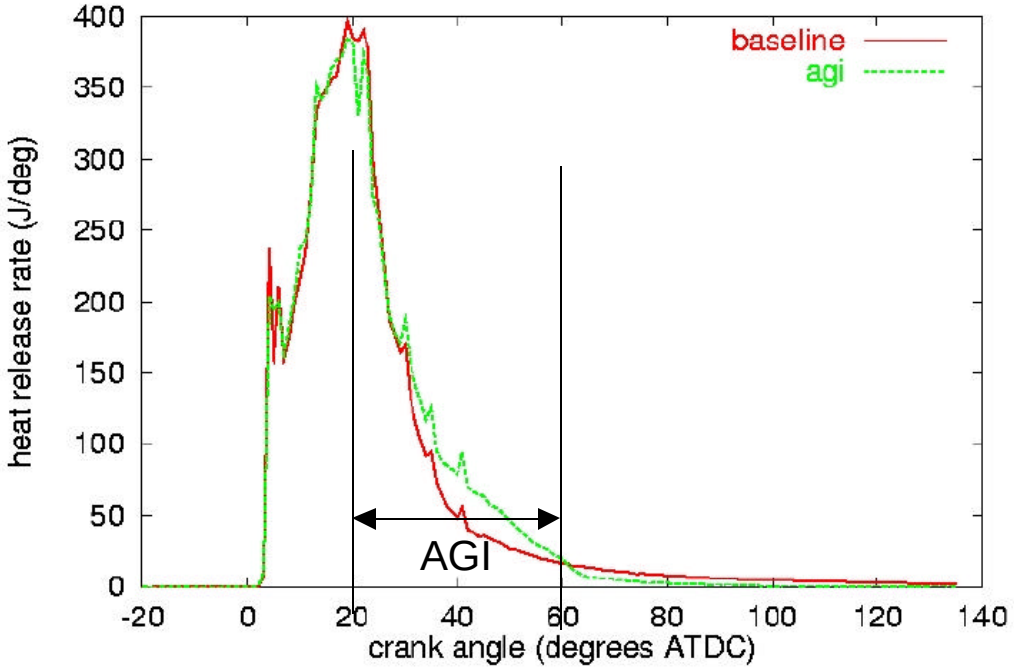




Run Conditions:

Beginning of oxygen-enriched air injection: 20° ATDC
Oxygen purity in the intake air: 25%
Start of fuel injection timing: Base timing (0° ATDC)
Test condition: Caterpillar Mode IV (1600 rpm, 43 hp)

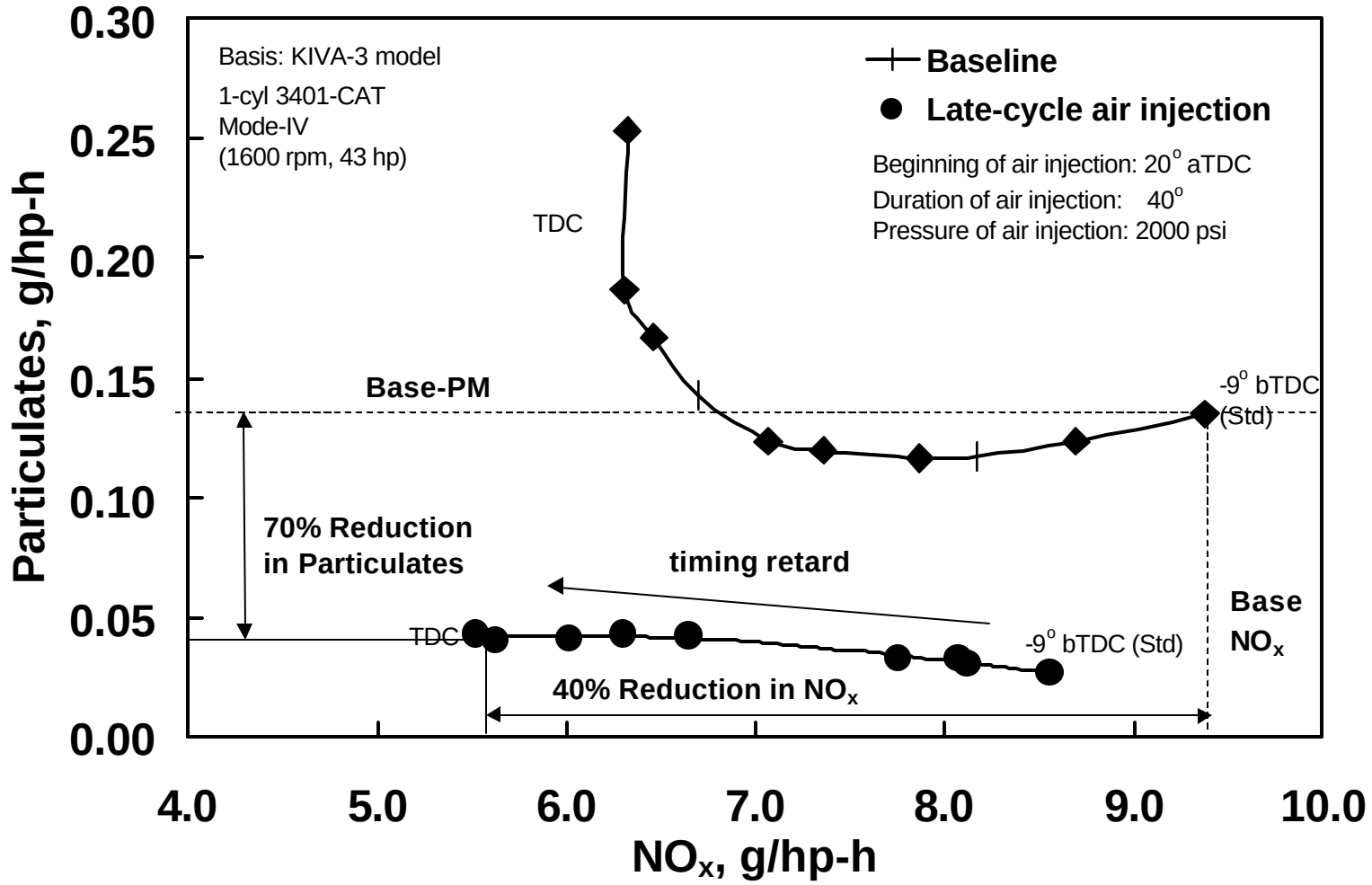
……. With Increased Heat Release.



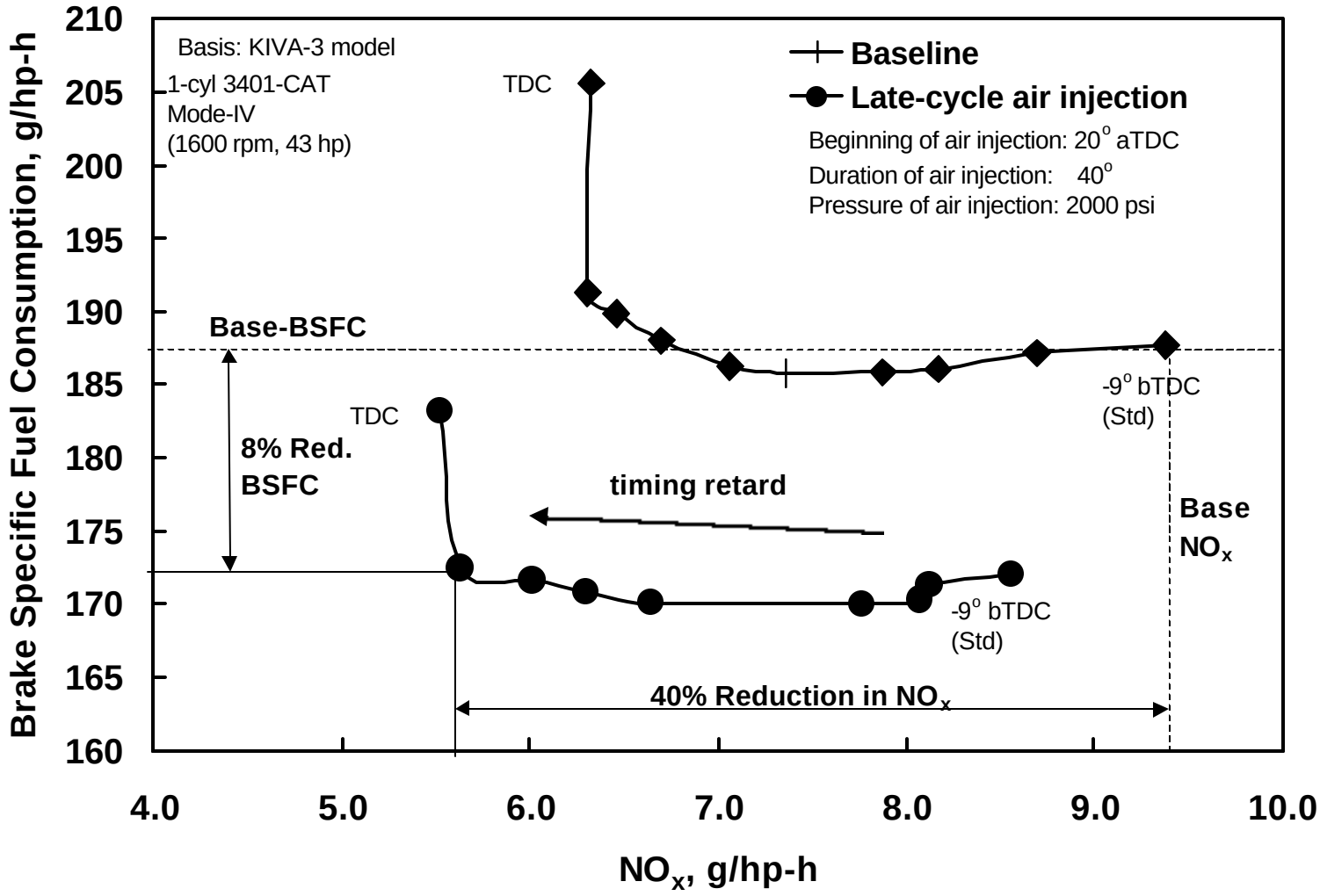
Run Conditions:

Beginning of oxygen-enriched air injection: 20^{o} ATDC
Oxygen purity in the intake air: 25%
Start of fuel injection timing: Base timing (0^{o} ATDC)
Test condition: Caterpillar Mode IV (1600 rpm, 43 hp)

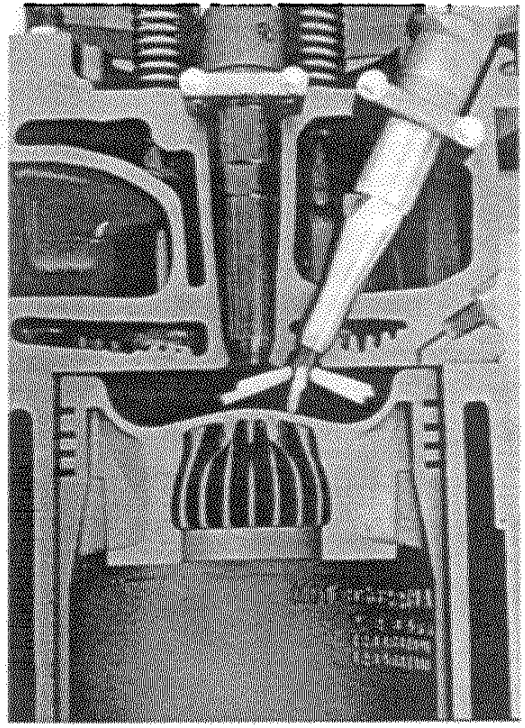
Simultaneous Reduction of NO_x and PM with Optimized Late-Cycle Air Injection and Fuel Injection Timing and …….



……. Potential Gain in Efficiency.

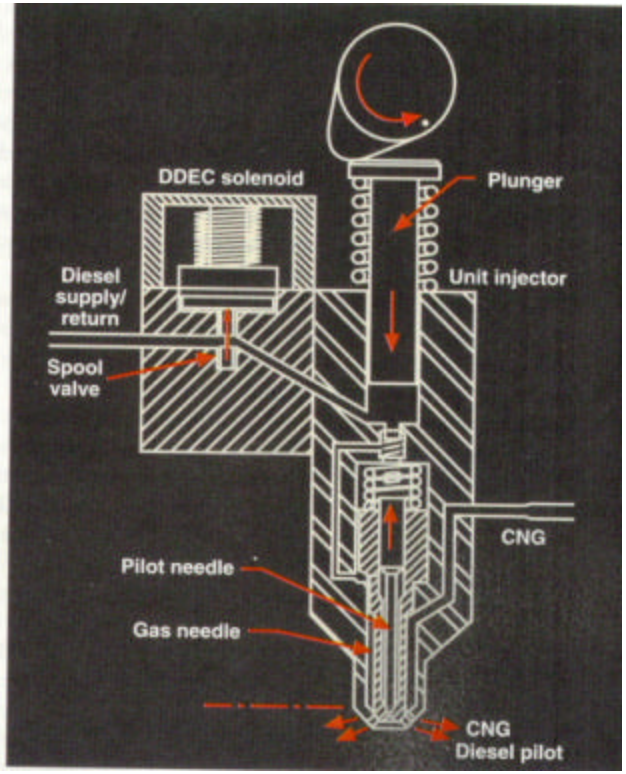


In-Cylinder Late-cycle Air Injection System is Feasible



Cutaway Picture of the EMD 1-710 Engine

Example: A natural gas injector with diesel pilot injection arrangement @ SwRI (gas-rail project) can be modified



Example: Westport high-pressure direct injector to inject both diesel and CNG from a single injector can be modified

Accomplishments

MODELING

- ANL-CAT-ERC developed a test matrix for KIVA simulations
- Completed parametric results with a centrally located auxiliary gas injector and 60 degree sector
- Identified different parameters that have potential to reduce NO_x and PM emissions simultaneously

EXPERIMENTAL

- Constructed Engine Test Facility
- Commissioned CAT Engine
- Presently Running Engine Baseline Conditions

Future Plans and Milestones

Modeling Phase

- Use as Guidance for Identifying & Understanding Mechanisms
- Full 360 Degree Simulations

Experimental Phase

- Baseline Engine Emissions
- Gas Injector Experiments Correlation w/ Model
- Optimization Studies - AGI, Fuel, & Intake Air Systems