Vehicle Engine Technology: Advanced Combustion Regimes and Fuel Requirements (Engine Guy's Wish List)

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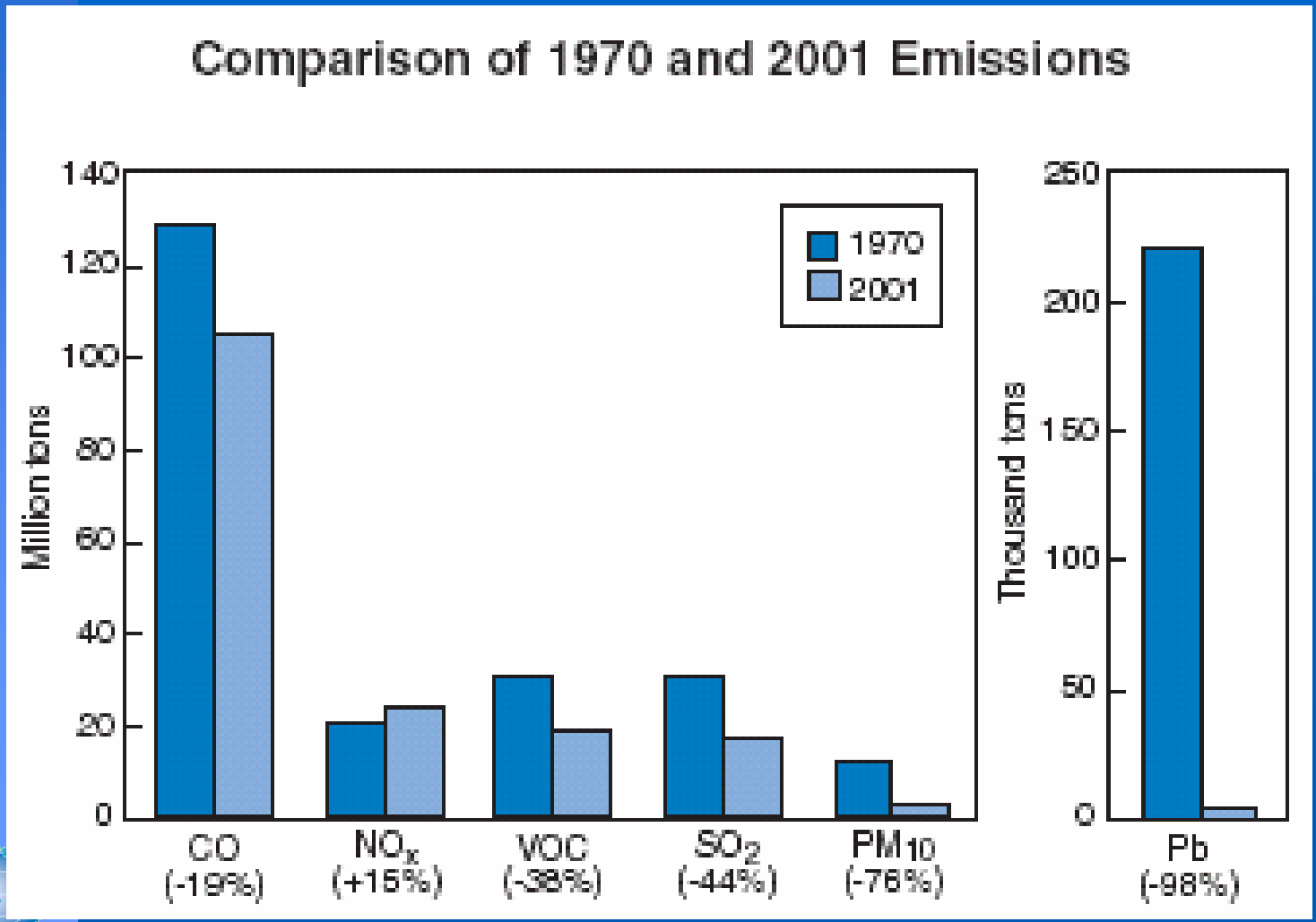
Effect of Regulations on Ambient Air Quality



Premise

- Future US emissions Standards will be More Stringent than Currently Planned
  - TIER II is not the Last of the Light Duty Standards
  - 2010 HD Standard Can Be Changed as soon as 2014
  - Off-Road TIER 4 Likely to Follow 2014 HD On-Road

Background
Engine Combustion Modes

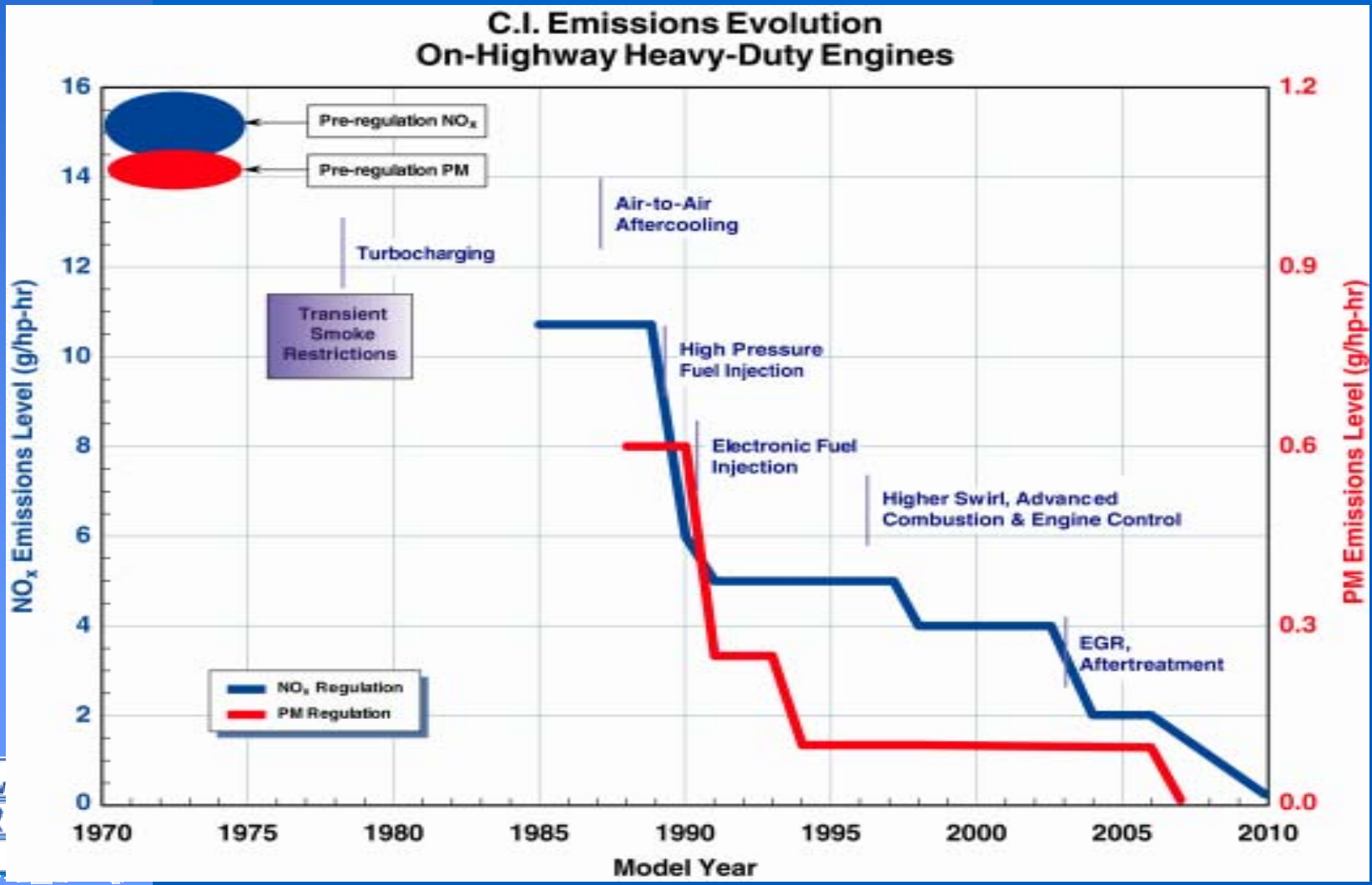
- Three Fundamental Modes of Combustion in Reciprocating Engines
  - Diffusion Combustion
    - Conventional Diesel
    - Stratified Direct Injection SI
  - Flame Propagation Combustion
    - Conventional Gasoline SI
    - Lean Burn SI
  - Homogeneous Reaction
    - HCCI

Basic Question

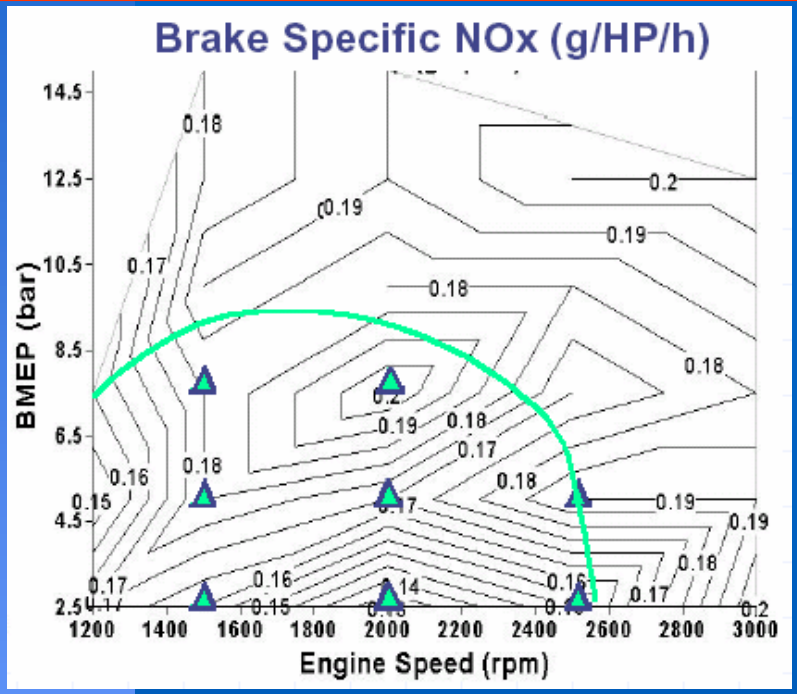
- How will future emissions regulations affect the selection of the most cost effective engine and powertrain system for the various on-road and off-road applications?

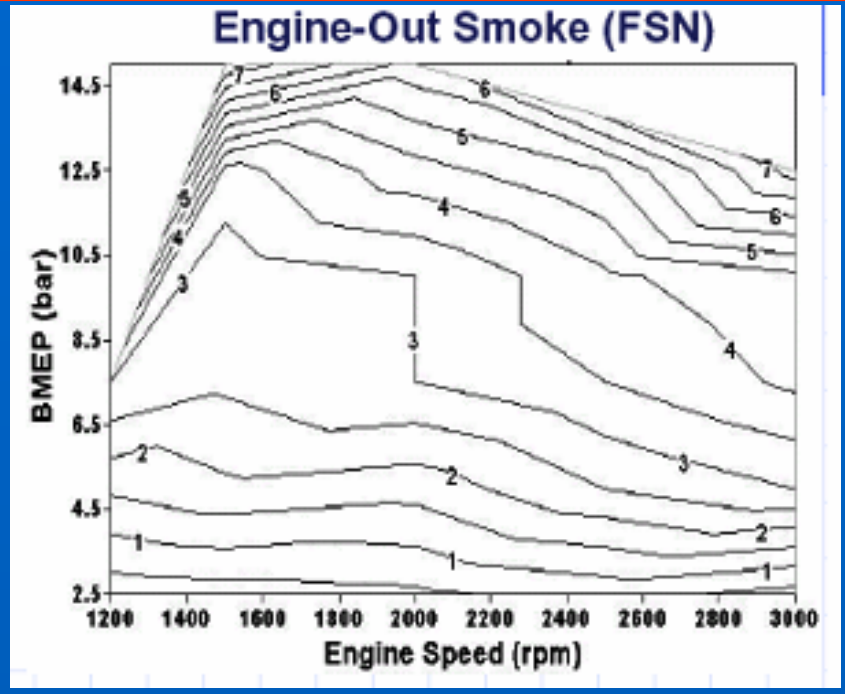
Diffusion Burn Engines

History of Diesel Emissions Technology Evolution



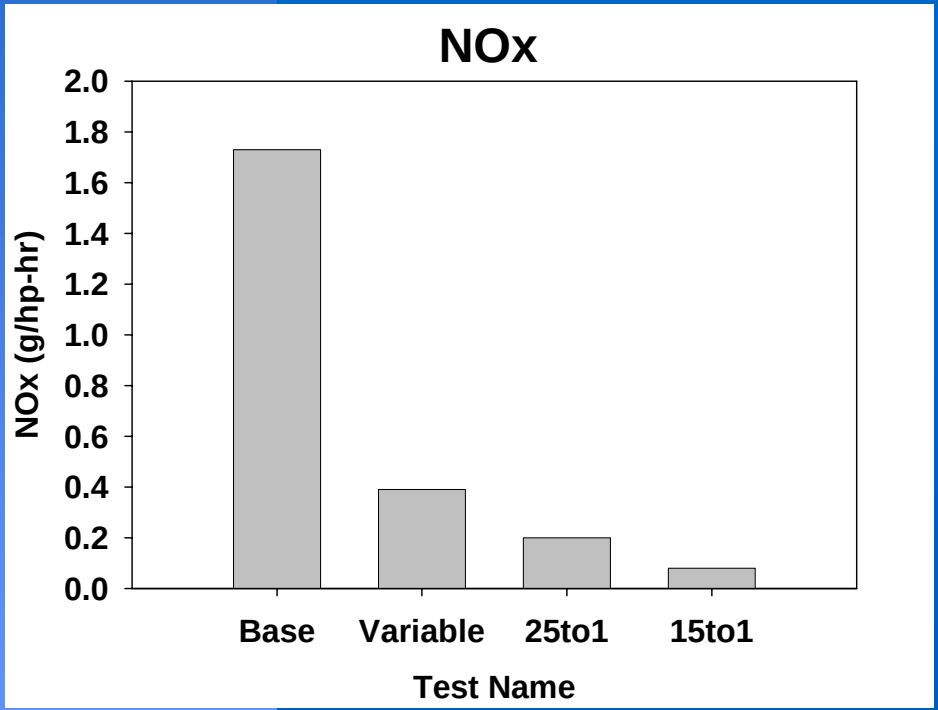
Promising Approach - EPA-Ford Data

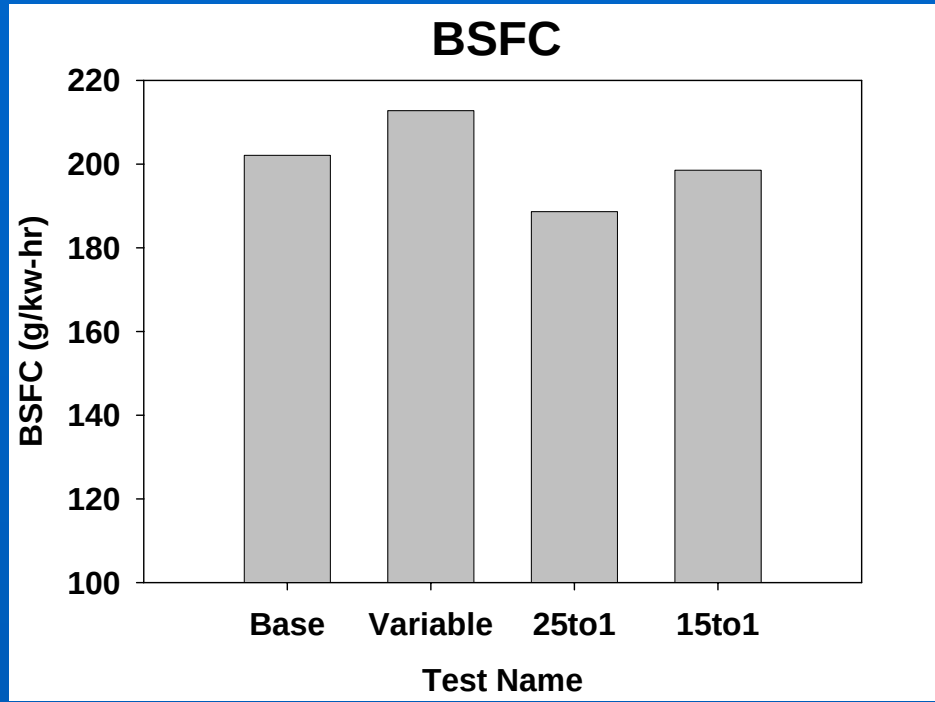




Type	4-cylinder, 2 valve/cyl OHC
Displacement	1896 cm^3
Bore	79.5 mm
Stroke	95.5 mm
Comp. Ratio	19.5:1
EPA Fuel System	- Hydraulically Intensified
Injector Location	- 7mm offset w/ 26° Inclin.
Boost Systems	- externally supplemented ($P_{exh} = P_{int} + 0.1Bar$)
	- partial map TC matched (Initial effort)

Massive EGR





- Baseline Engine Around 2 g/hp-hr
- BSFC Penalty with Variable Due to Back Pressure Increases
- 25:1 A/F Produced Lots of Turbine Energy
- 15:1 A/F Lowered the Air Flow and Boost Requirements

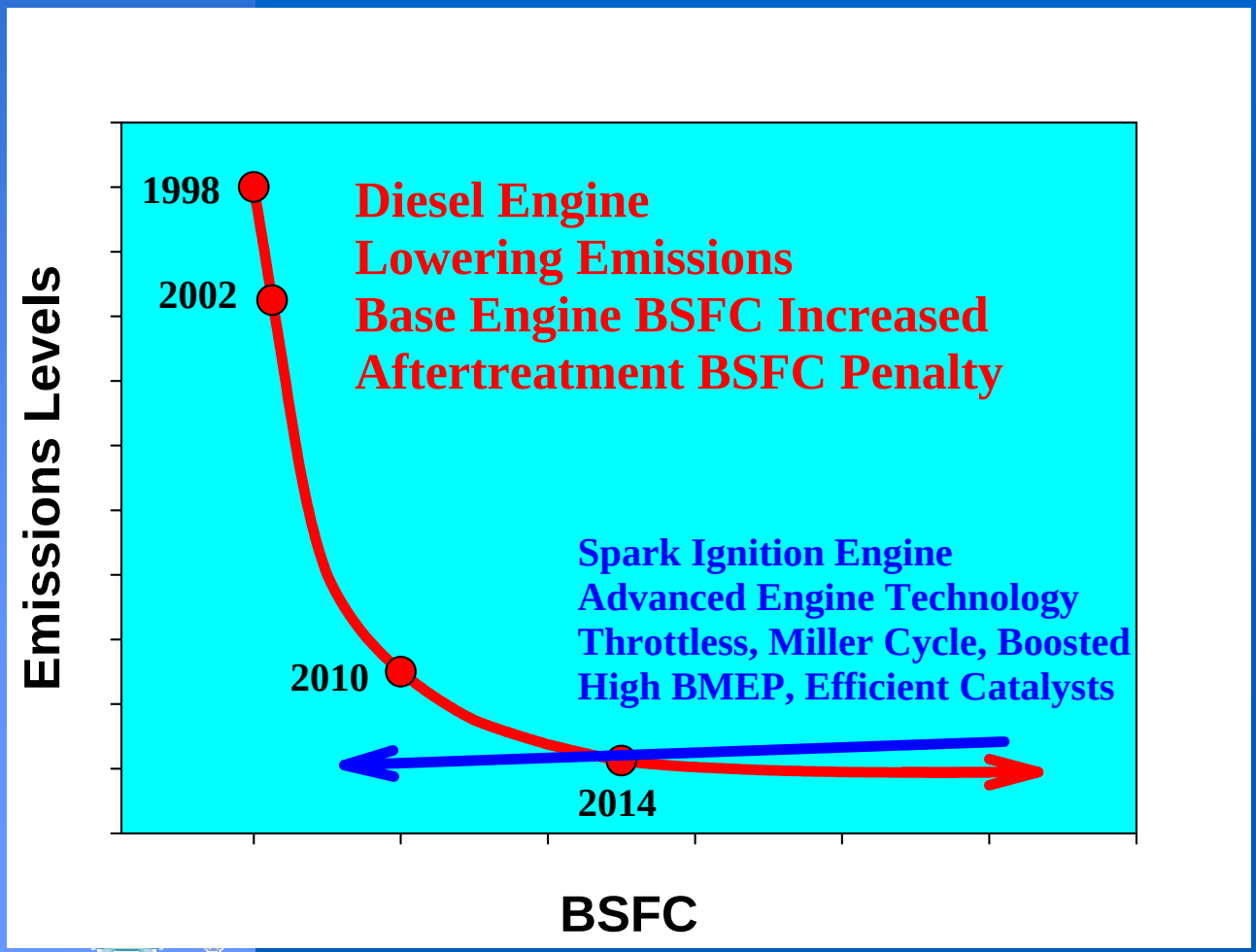
Diffusion Burn Engines - Summary

- Predictions for Beyond 2010
  - Cost Increases of $13,700
  - Efficiency loss of 19%
- Can this be improved?
  - Yes
    - Need Higher CN, Lower Aromatic Fuel to Allow Higher EGR Levels, More Advanced Injection Timing, and Lower Engine Out NOx and PM
    - SCR Can Reduce the Efficiency Penalty but Need to have Urea Supply Proportional to Fuel Usage

Flame Propagation Engines

Diffusion versus Flame Propagation Combustion

At What Emissions Level do the efficiencies Converge?



Efficiency Enhancement of Gasoline Engines

- Throttle-less Operation
- Increase BMEP Level
- Knock Mitigation
- Increase CR
- Advance Ignition Timing
- High Energy Ignition

ISB -Gasoline Comparison

Efficiency Comparisons

	1998	2002/2004	2007	2010	2014
ISB	37	36.3	35.5	32.6	30
D-C V10	25		31.5	31.5	31.5

Cost Comparisons

	2002/2004	2007	2010	2014
D-C V-10		2200	2200	2200
ISB	1850	4700	7400	8650

- All of the Gasoline Technologies Exit Today, but Knock Mitigation Requires Significant Development
- Costs for Gasoline is Only for Efficiency Improvements, Do Not Cover Needed Durability Improvements

HCCI Engines

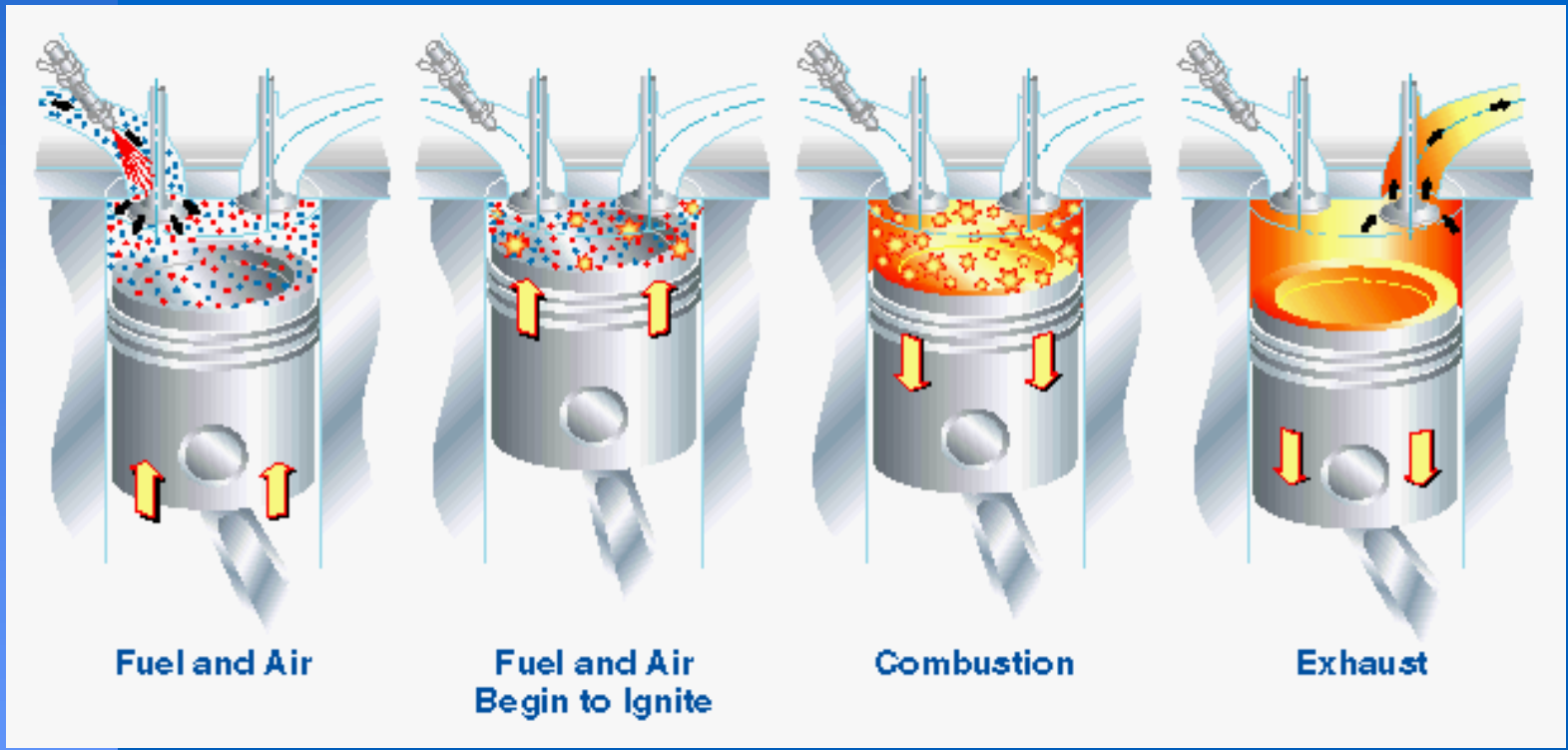
Engine Developers Toolbox Modes of Combustion

- Flame Propagation
  - Gasoline SI Engine

- Diffusion
  - Diesel Engine

- Homogeneous Charge Compression Ignition (HCCI)

HCCI



- Fuel & Air Charge Undergoes Compression
- Spontaneous Reaction Throughout Cylinder
- Low Temperature Reaction Creates Low NO_x

17

Fundamentals of HCCI Reaction

- Ideally, a Homogeneous Fuel-Air Mixture is One in Which the Composition and the Thermodynamic Conditions are Uniform Throughout the Reaction Phase
  - Reaction Starts When the Thermodynamic Conditions are Sufficient to Initiate Chain Branching Reactions
  - Reaction Rates and Reaction Duration are Kinetically Controlled

Fundamentals of HCCI Reaction

- Practical Fuel-Air Mixtures Have Both Compositional and Thermodynamic In-Homogeneities
  - Reaction Begins in the Fuel Richest and the Highest Temperature Locations
  - Reaction Rates and Reaction Duration are Affected by Mixing and Heat Transfer

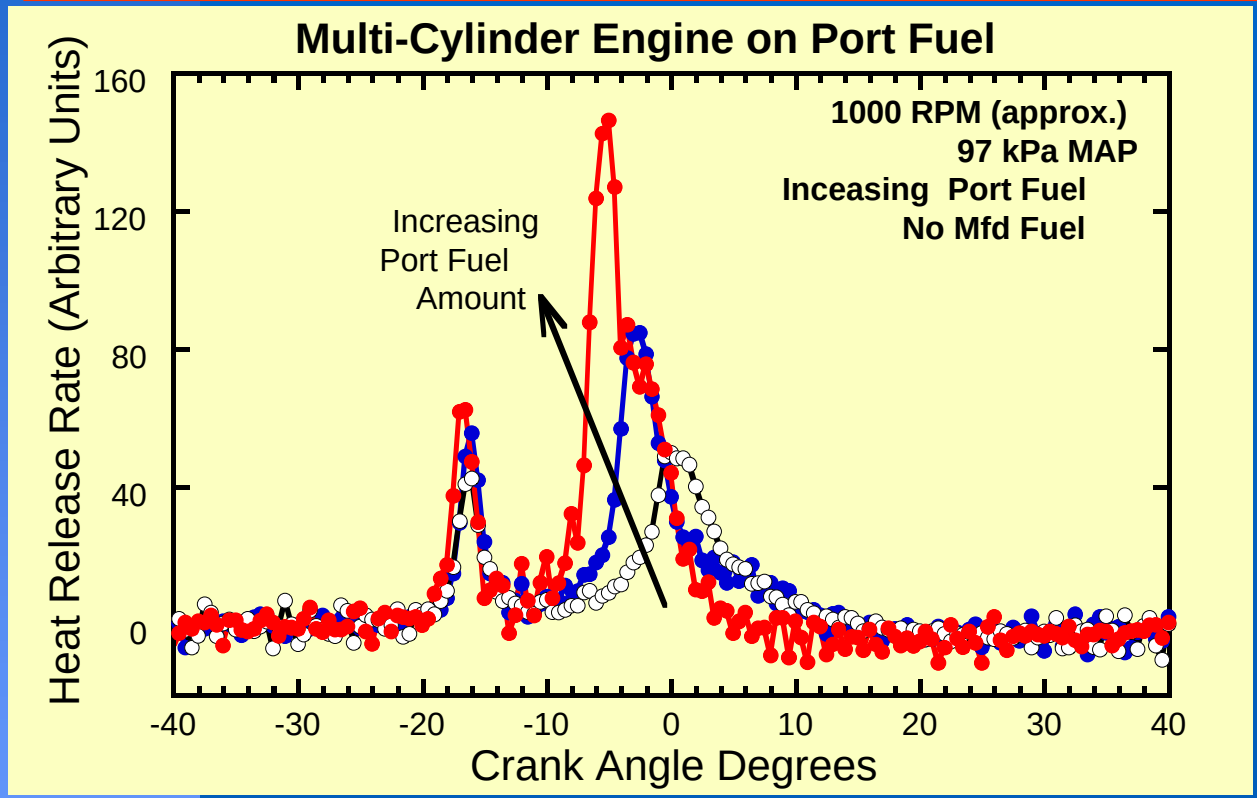
HCCI Rules
Fuel Related

- All Fuel Must Be Evaporated Prior to the Start of Reaction
  - Liquid Fuel Drops Burn As Diffusion Flames With High NOx and PM
- Fuels Must Have Start of Reaction Temperatures and Ignition Delay Times (Ignition Characteristics) Such That Reaction Begins at TDC

Current Situation
(General Comments)

- HCCI Developments Based Around Specific Fuels
  - Primary Focus on Gasoline and Diesel Fuel
- Near Term HCCI Application Likely in Mode Switching Engines
- Full-Time HCCI Operation Possible Only with Specific HCCI Fuel

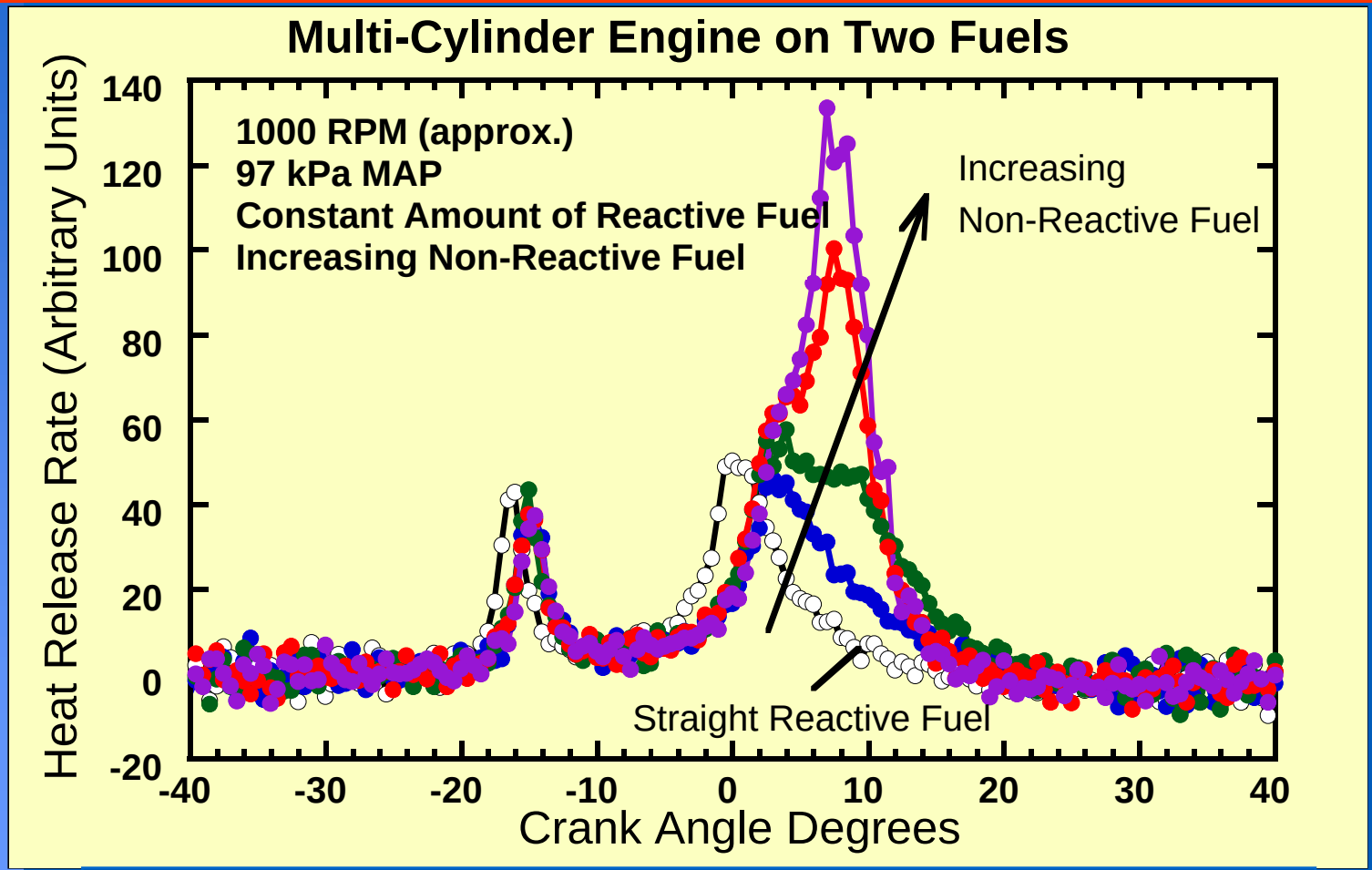
Multi-Cylinder-Single-Fuel HCCI



Typical HCCI Combustion Phasing Advances With Increasing Load and Vice-versa

- Varying the Amount of Port Fuel (Reactive) Changes the Combustion Phasing When No Mfd. Fuel (Low-reactivity) Is Used
- This Is the Typical Problem Experienced With HCCI Combustion of a Single Fuel

Multi-Cylinder-Fuel-Blending Approach



Dual-fuel HCCI Combustion Phasing Is Not Affected by Low-reactivity Fuel Amount

HCCI Fuel Requirements

- Gasoline Like Boiling Point Distribution
- Ignition Quality (Autoignition Temperature) Between Gasoline and Diesel Fuel

Thank You