# DILUTE MIXTURES and EGR

Workshop on Techniques for High-Pressure Combustion

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Important to remember why we are here:

High EFFICIENCY and Low EMISSIONS

with good performance, power density, etc.

September 1, 2011

# Session Line-up

**Topics closer to end-use:** engine simulation, autoignition, and *real world* challenges and opportunities

| | | |
|---|---|---|
| 8:00 AM | Introduction | |
| 8:15 AM | Brad VanDerWege (Ford) | *EGR Effects on Combustion in Boosted SI and CI Engines* |
| 8:45 AM | Carl Hergart (Caterpillar) | *Challenges and Opportunities in Heavy-Duty Combustion* |
| 9:15 AM | Robert Dibble (UC Berkeley) | *Effects of EGR and High Pressures on Autoignition, Spark Ignition, and Microwave Assisted Spark Plugs* |
| 9:45 AM | Coffee Break | |
| 10:15 AM | Michael Davis (Argonne) | *Chemical-Kinetics Toolkit for Engine Simulations* |
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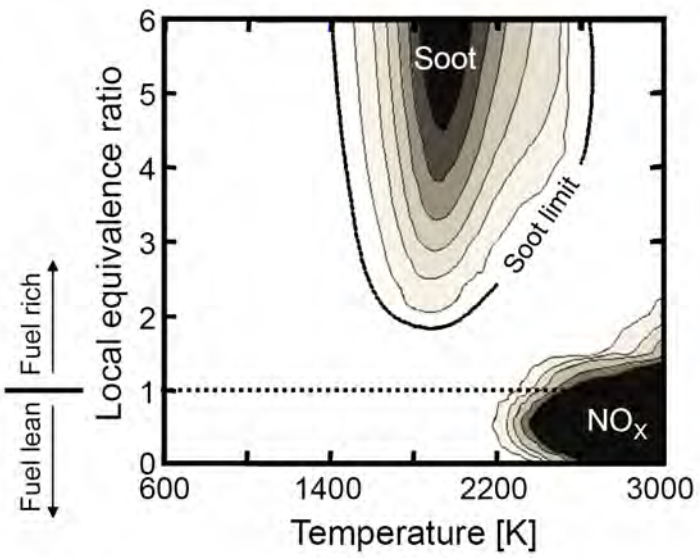
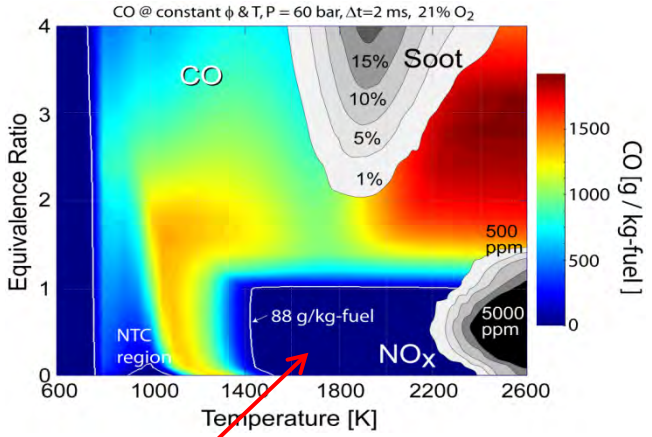
| 11:15 AM | Discussion | |

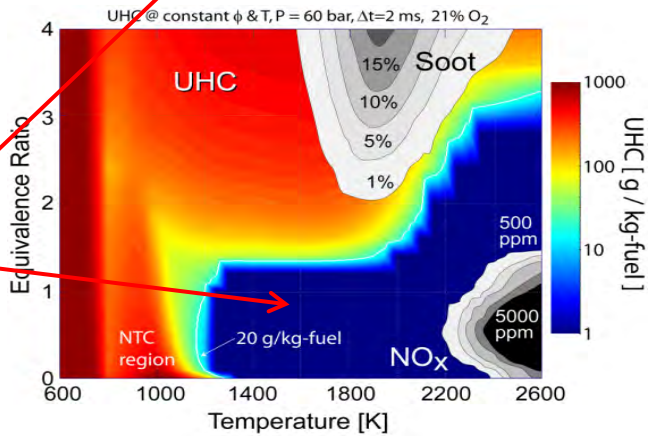
# High Dilution and EGR provide pathway to low temperature combustion (LTC) for high efficiency with low emissions

LTC creates reacting mixtures in-cylinder that avoid soot and NOx formation …




…while at the same time avoid CO and UHC emissions.




Charge must end up in this region after combustion is complete



Slide adapted from DOE presentation, Gurpreet Singh *et al.*

# Many many challenges

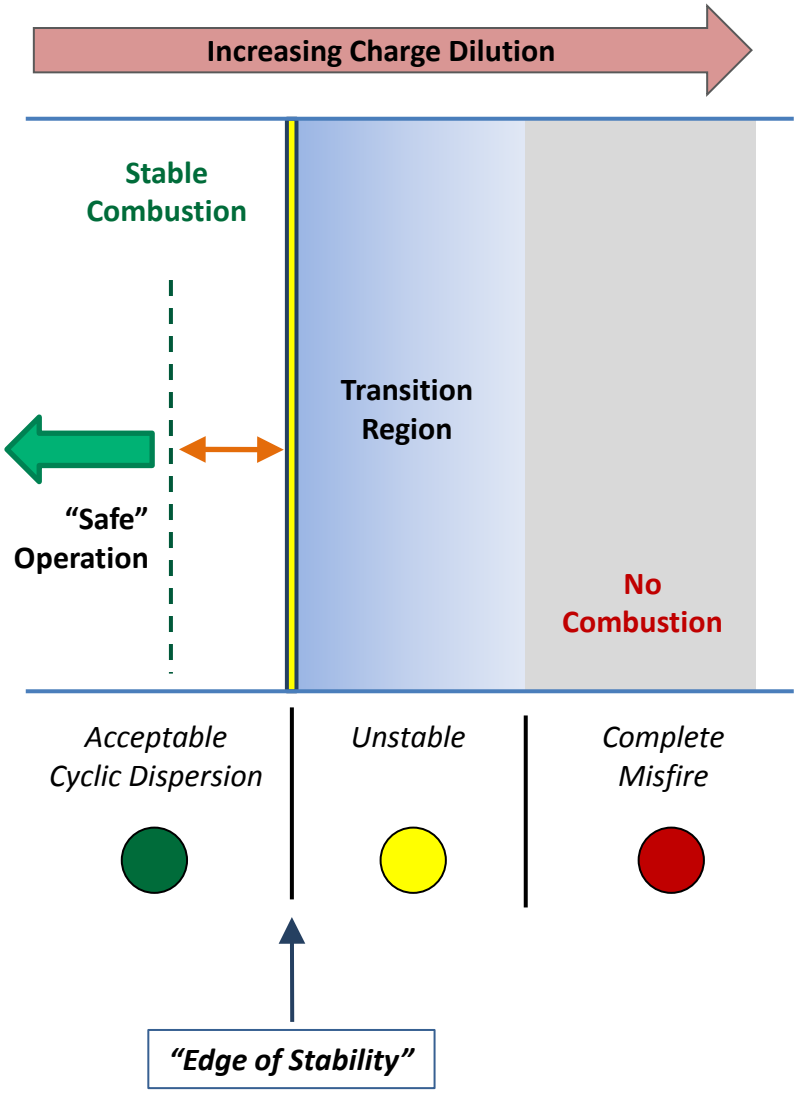
- **Precise control of boundary conditions**
  Turbo-machinery, variable valve actuation, heat exchangers
- **Higher in-cylinder peak pressures**
  Materials
- **Improved fuel injection technology**
  Injector architecture, faster response
- **Increase in HC, CO emissions**
  Low temperature catalysts
- **Stability and controls**
  Cyclic dispersion, adaptive controls, advanced sensors, etc.
- **And many more …**

**A better understanding of processes as well as faster and more accurate models will help with many of these challenges.**

# Stability and control are potential roadblocks to *fully optimized* high dilution operation

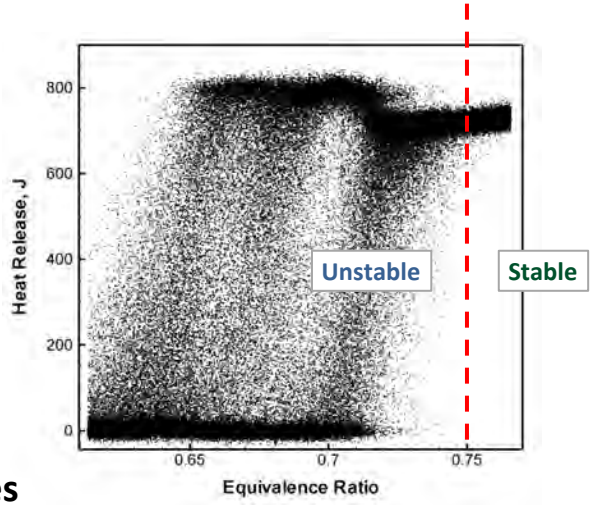
- **Practical implementations operate well away from the "edge of stability".**
- **Cyclic dispersion driven by stochastic and deterministic processes.**
  - Very nonlinear relationship for conditions consistent with many LTC concepts.
  - Deterministic processes act as nonlinear amplifier to stochastic variations.
- **Further complicated by cylinder imbalances.**
  - Cyclic dispersion may amplify cylinder-to-cylinder imbalances.

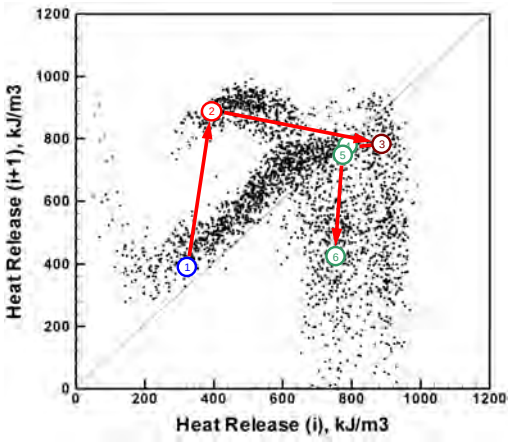
➡ **Improved control will require an improved understanding of instability mechanism (*i.e.*, chemical and physical processes).**



# Many opportunities require better understanding of chemical and physical processes

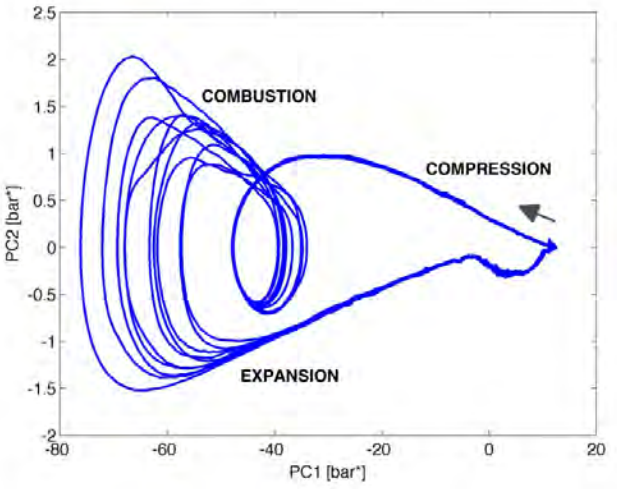
- **Operation near the "edge of stability"**
  - Avoid unintended excursions which may damage or destroy the engine, aftertreatment, and energy recovery systems.
  - ➡ *Example showing the **"edge of stability"** for lean burn SI combustion.*




- **Transition and stabilization of LTC modes**
  - Transition between conventional and LTC operation.
  - Operation under inherently unstable conditions may provide efficiency and emissions benefit not possible without active control.
  - ➡ *Example of complex but **short-term predictable** patterns in spark assisted HCCI combustion.*

- **Avoiding abnormal combustion events**
  - Pre-ignition events potential roadblock to extreme down-sizing and down-speeding.
  - Advanced time-series analysis for prediction and avoidance.
  - ➡ *Example phase-space reconstruction one method with potential to predict onset of abnormal combustion events.*



# To this end … advances in sensor technology and onboard computer power are expanding the possibilities for high speed predictive control

**Measurement**

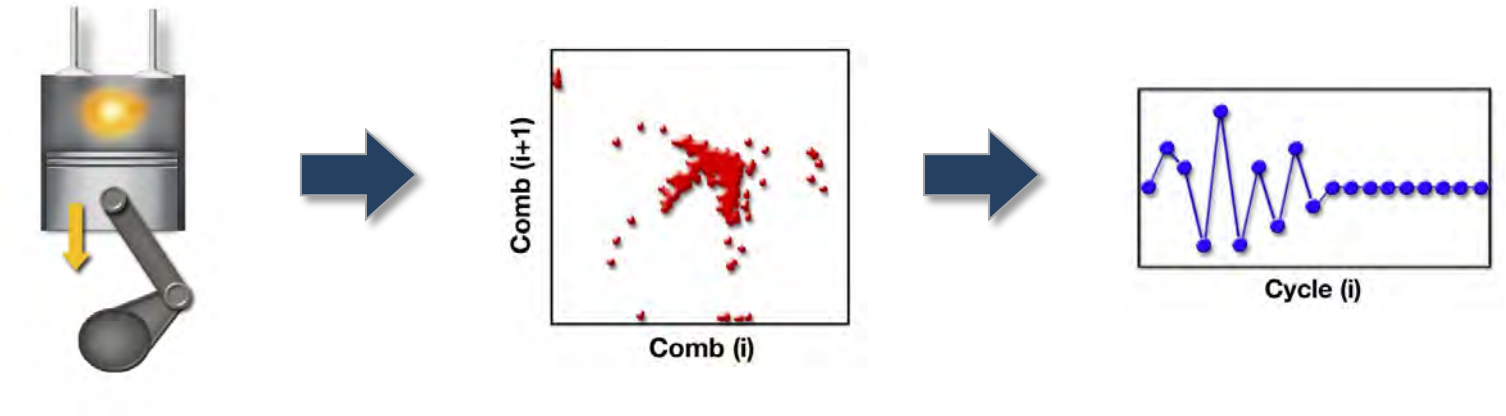
- In-cylinder pressure
- Ionization
- Acoustic
- Other

**Analysis**

- Pattern recognition
- Prediction
- Modeling

**Control**

- Avoid certain states
- Short- and long-time scale feedback perturbations
- Pro-active




**Improved understanding and models needed to make the most of these advances!**

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