# The Next ICE Age
# DEER 2012

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# General Motivation Driving Technology Development

**Maximize efficiency within the constraints of emissions.**

# Efficiency Quest Overview

- Losses, efficiency decrements, can be identified
- Compression and expansion are wonderful processes thermodynamically
  - Their use, especially expansion, should be maximized
- Combustion irreversibilities of approximately 20% of the fuel's availability are unavoidable
  - This is not a combustion efficiency issue
- Keeping in-cylinder temperatures low is thermodynamically very advantageous
  - Directly impacts extractable expansion work for a specified expansion ratio, which works toward minimizing exhaust energy loss
- Heat transfer is a difficult loss to contend with – low in-cylinder temperatures help in two ways
  - Minimized the magnitude of the heat transfer
  - Minimized the availability of the heat transfer energy lost
- Gas exchange work is a necessary expenditure because the engine is a chemical processes.
  - Increases in pumping requirements for any reason carries a fuel economy penalty
- No stone can be left unturned
  - Crevice volumes, friction, rotating inertia, transients, etc.

# Where To From Here?

- **State of the art engines are becoming very good and approaching stretch goals.**
- **Challenge:**
  - **Continue to "eek" out further efficiency gains**
  - **Expand these high efficiency operating regimes to larger portions of the engine operating map, and for all operational scenarios – transients**
- **Introduce two activities**
  - **Gasoline Direct Injection Compression Ignition**
  - **Transient response**

# Gasoline Direct Injection Compression Ignition*

- **GDICI is a low temperature combustion (LTC) strategy that offers the potential to increase efficiency and reduce both NOx and PM emissions**

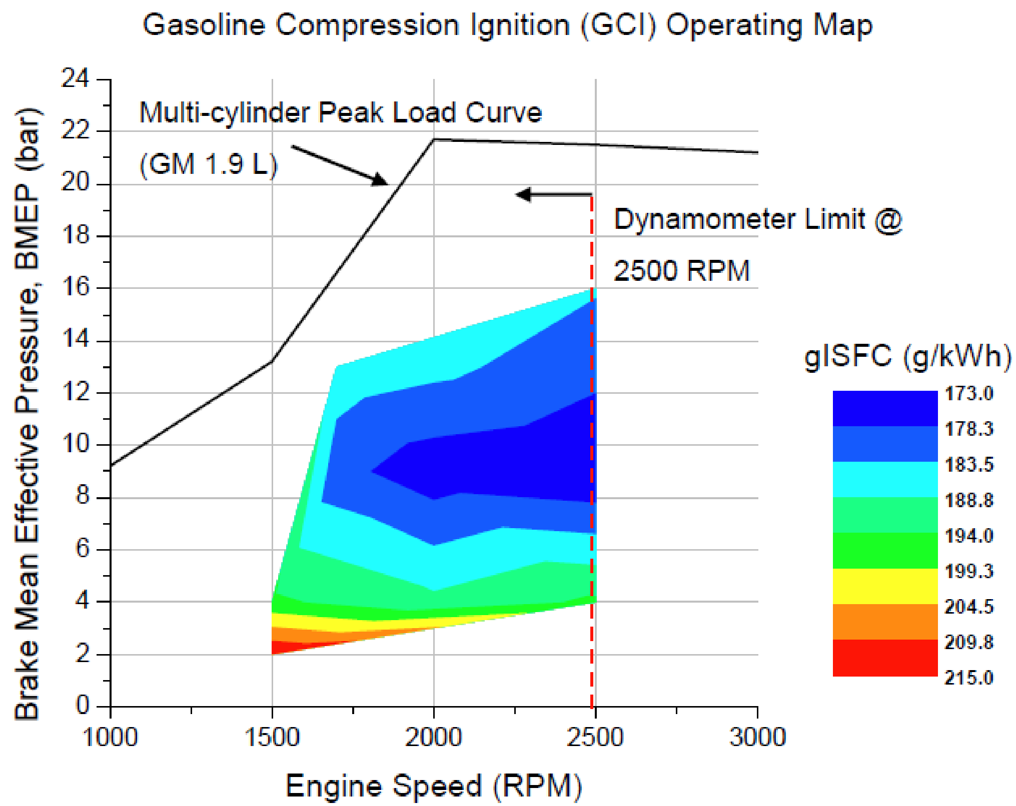
- **This combustion strategy is highly dependent upon direct injection of gasoline near TDC (within 40° BTDC)**
  - **The timing and duration of this near-TDC injection can be tailored (based on speed and load) to create an optimized equivalent ratio distribution leading to a stable, staged combustion event (low noise)**

- **Unlike diesel LTC, GDICI requires no EGR up to 7 bar net IMEP, and PM emissions remain <0.1 g/kg-Fl at loads in excess of 14 bar net IMEP.**

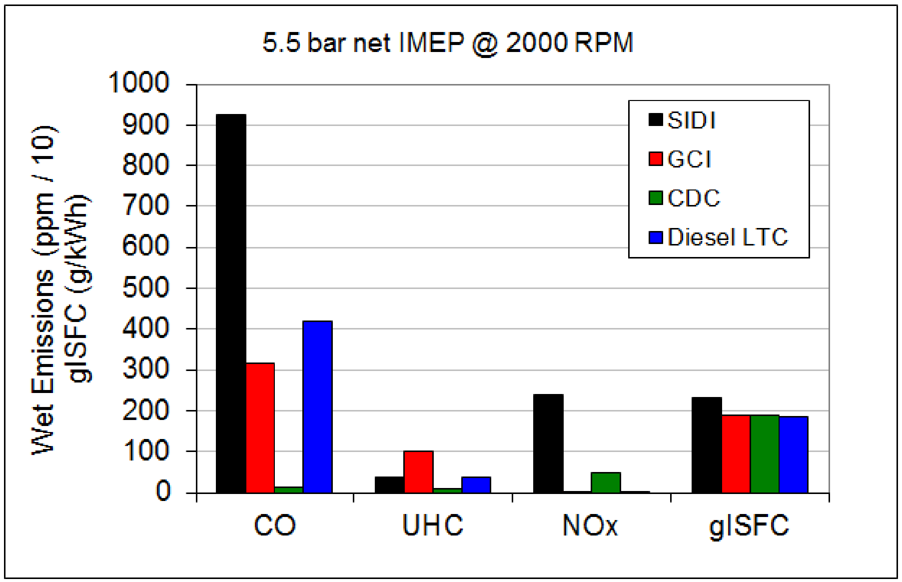

* GM-ERC-CRL and
DOE Contract DE-EE0000202

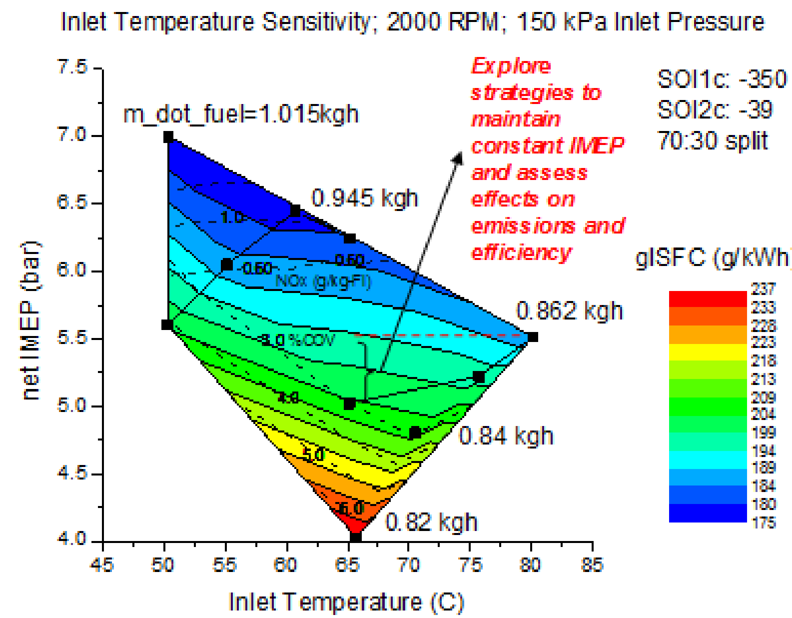
# LTC: Gasoline Compression Ignition

- **CFD served an important role during experimental investigations**
  - **Computations provided initial run conditions**
  - **Minimized risk to engine hardware**
- **Highlights**
  - **GCI combustion successfully demonstrated over a wide load/speed operating range (1500-2500 RPM, 3-17.8 bar net IMEP)**
  - **Maximum cylinder PRR<10 bar/deg (limit traditionally used within group)**
  - **NOx emissions < EPA US10 (~1 g/kg-FI)**
    - **e.g. 5.5 bar net IMEP, 2000 operation required no EGR**
    - **For comparison, diesel LTC required ~65% EGR**
  - **Near smokeless combustion up to 10 bar net IMEP (PM<<0.1 g/kg-FI)**
  - **Gross ISFC: 175-190 g/kW-hr**



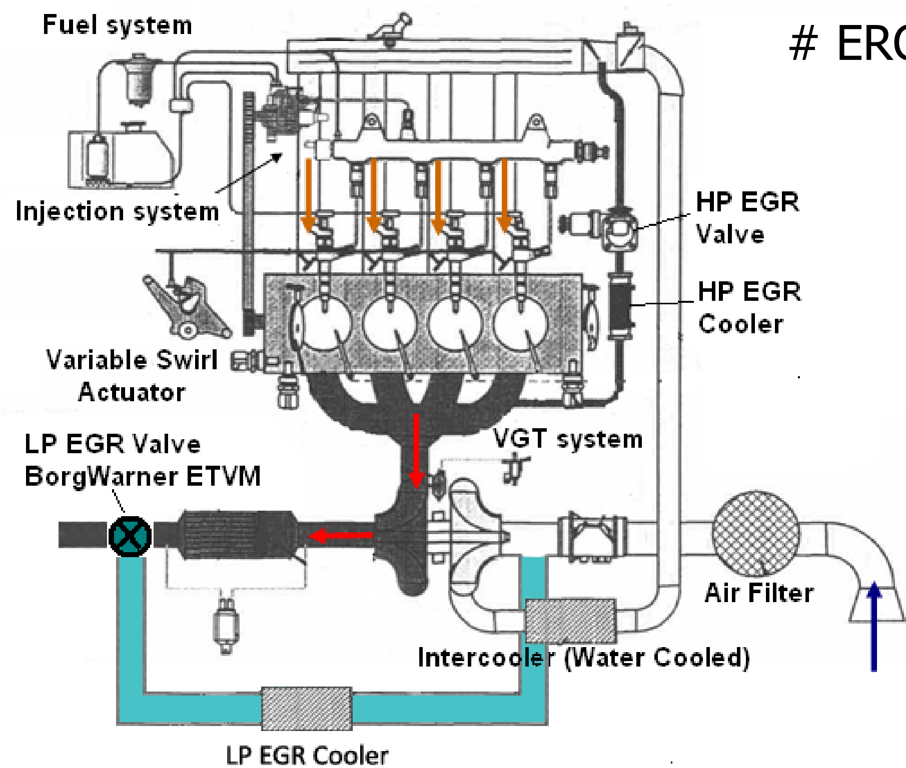
# Emissions are Low and Combustion is Controllable




- **Diesel efficiencies, with very low emissions**
- **Injection timing, pressure and split ratios give control robustness**

# Multi-cylinder Transient#




# ERC-DERC and DOE contract DE-EE0000202

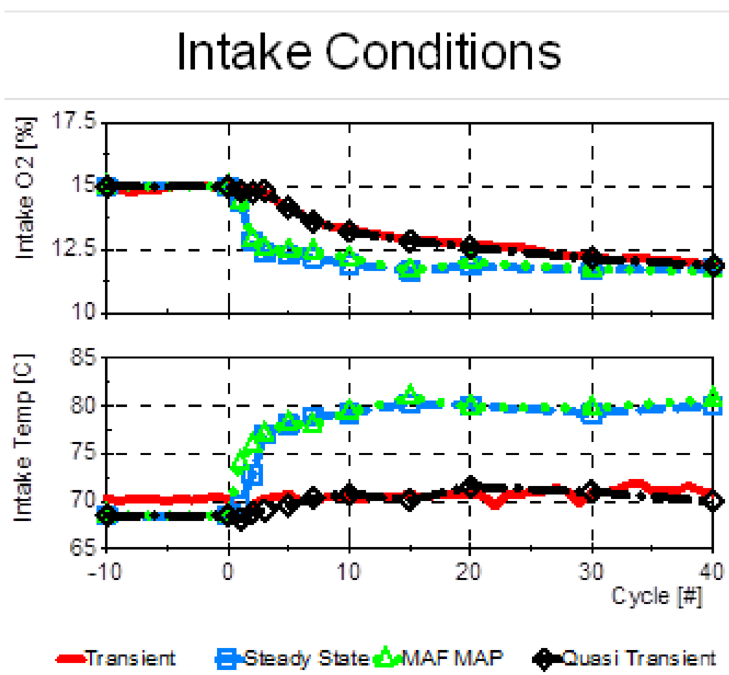
| | Steady State | MAF-MAP* | Quasi-Transient |
|---|---|---|---|
| Speed | X | X | X |
| Fuel Mass | X | X | X |
| MAP | | X | X |
| MAF | | X | |
| Intake O2 [%] | | | X |
| Intake Temp | | | X |
| Rail Pressure | | | X |

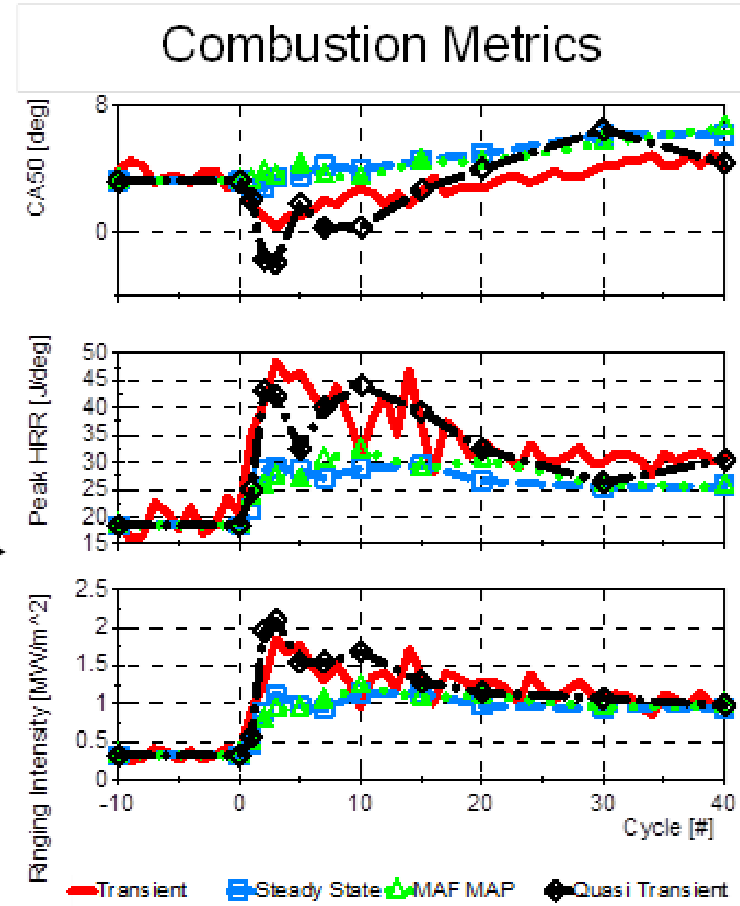
***Eastwood et al., SAE 2009-24-0147**

- Explore transient performance for LTC and combustion mode changes
- Identify and quantify the parametric differences between transient combustion and emission, and the values obtained from tests attempting is simulate transient performance via sequential steady state operating conditions

# Reproducing Transients with Steady State Operation (LTC operation)

- **O2 concentration at IVC is a critical parameter**
- **It is not properly assessed via MAF and ECU outputs**

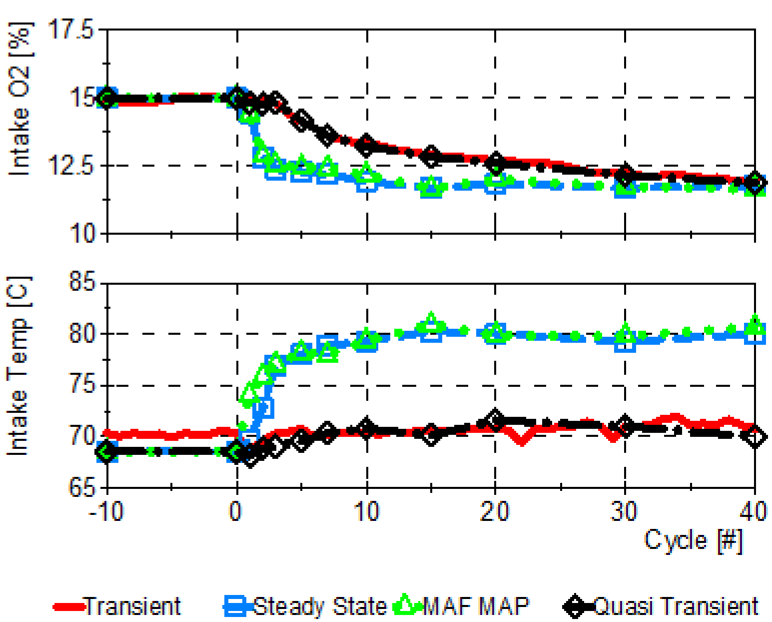


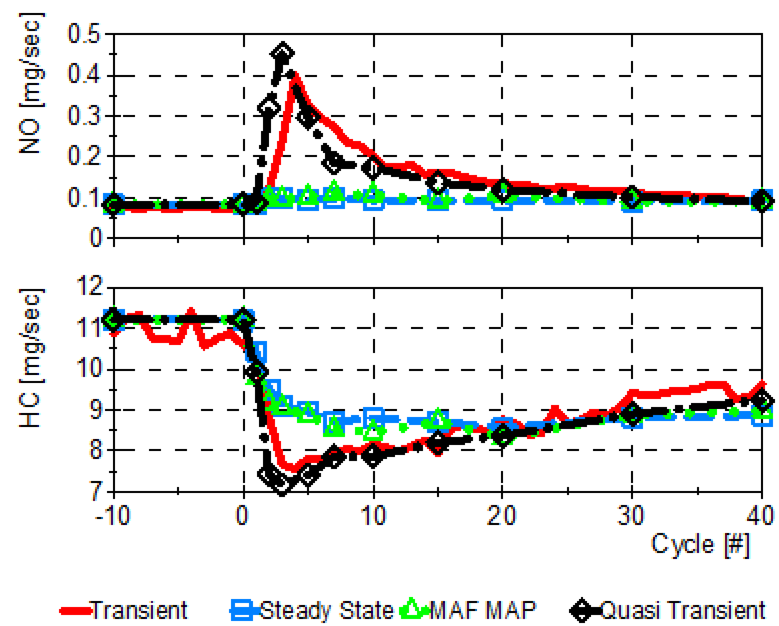
# Reproducing Transients – Emissions (LTC)

- **Emission trends for LTC transients are captured well when dilution at IVC (O2 concentration) is captured**
- **For complete reproduction of the transient results the effect of long term thermal transients must also be captured.**
  - **This is more important when the transient involves classis diesel combustion**

Intake Conditions




Emissions



# Thank you for your attention

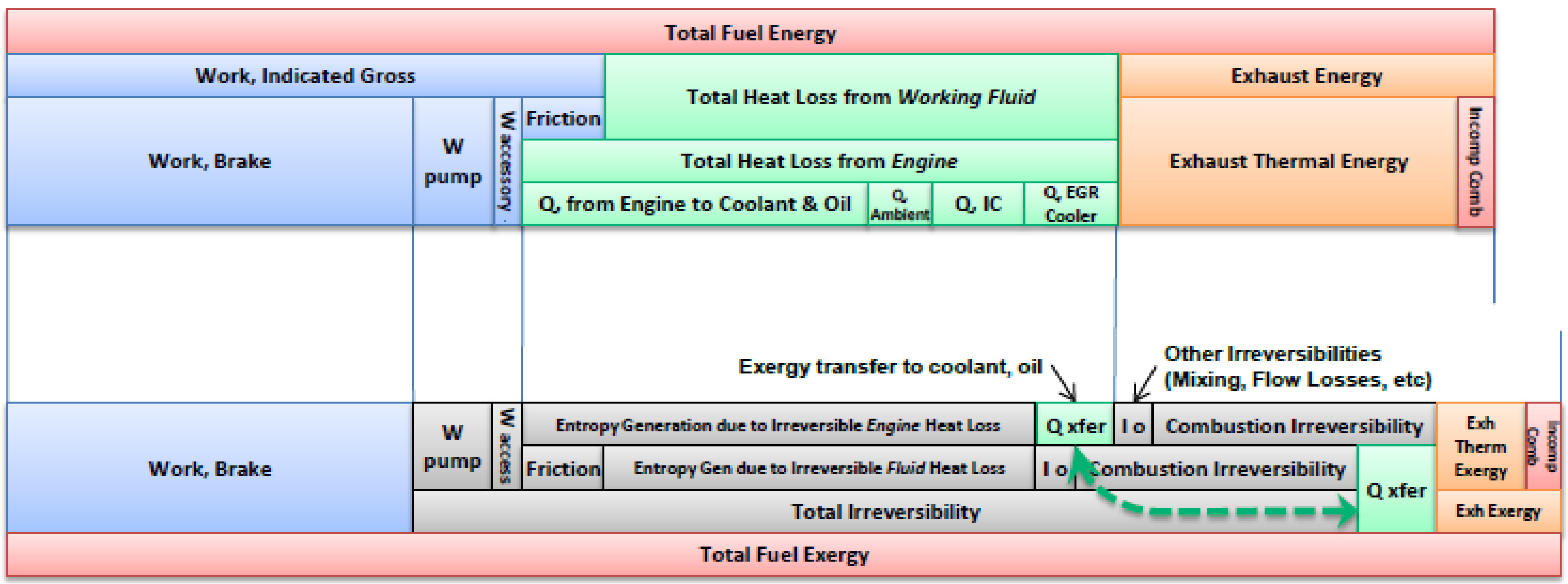
# Questions

- What technologies will be used to further increase engine efficiency? Focus of this presentation
- How will government regulations on fuel economy and emissions influence future engine technologies? In part, they will drive it
- Is there a potential role of diesel engines for light-duty vehicles? Yes
- What role will suppliers play in helping to achieve low-emission, high-efficiency engines of the future? A Big One
- Is there a role for fuels other than gasoline and diesel in the transportation sector?  If so, which fuels and which markets?  If not, why not? No short answer
- Will consumers accept alternative fuels for light-duty vehicles? If they are convenient, available and affordable
- Do you foresee a large role for hybrid and electric vehicles? Yes
- How can modeling and simulation improve engine efficiency? This presentation

# Tracking Energy and Exergy Flows

- **No stone left unturned**
  - **Some losses we must accept, e.g. combustion irreversibilities**
  - **Systematically work to maximize expansion work, and reduce other irreversibilities**
    - **Stretch goals have been identified – giving road maps on pathways to maximizing efficiency**
  - **Understand, and take advantage of, coupling of energy/exergy flows and emission abatement technologies**

1st Law Energy Balance




2nd Law Exergy Balance

* From K Dean Edwards, et al., Oakridge National Laboratory, DEER 2011