# Designing the Clean and Fuel Efficient Engine for the Twenty-First Century

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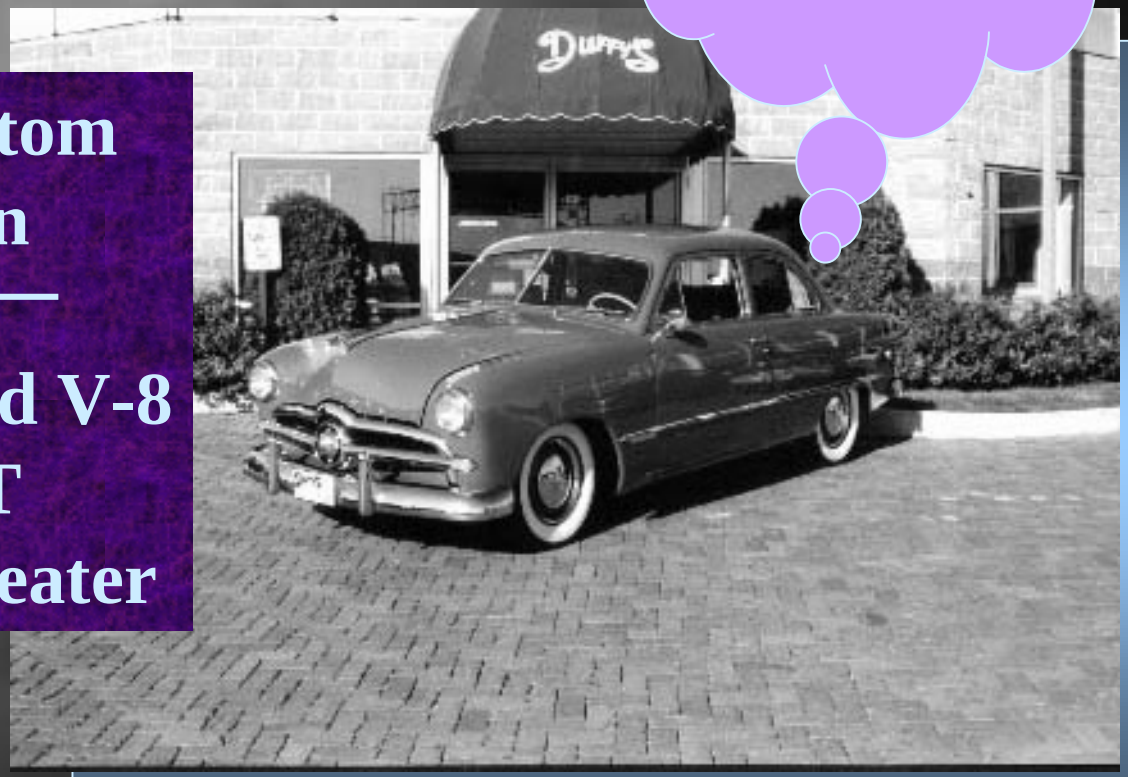
# Fifty Years Ago…

10(?) mpg
4 gpm NOx
8 gpm HC

**1949 Ford Custom Tudor Sedan**

**239 CID Flathead V-8**
**3-speed M/T**
**“Magic Aire” Heater**



# The Federal Role in Efficiency & Emissions

**Enabling Policy**
**( tax credits )**

**R&D Partnerships**
**( PNGV )**

**Regulatory Policy**
**( CAFE, Tier 2 )**

**Future Clean**
**Vehicle Technologies**

# Defining "Efficient":

- 80 mpg
- Meets Tier 2 emissions standards
- Meets all Federal safety standards
- Size, performance, cost of ownership comparable to today's midsize family sedans
- Implies leapfrog technology (engine, drivetrain)

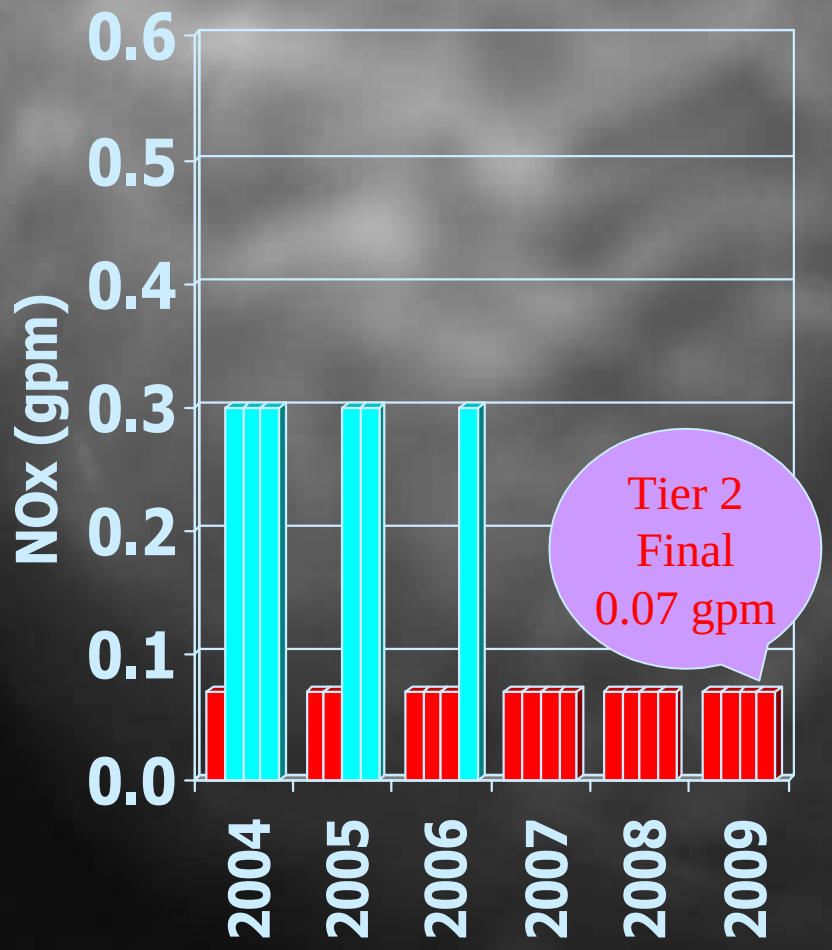
# Defining "Clean": Tier 2

- Establishes 7 certification emission bins applicable to all light duty vehicles
- Establishes interim & final manufacturer fleet average NOx standards
- Heavier light trucks get longer, but …
- …by 2009, eliminates explicitly different standards for car & light truck categories

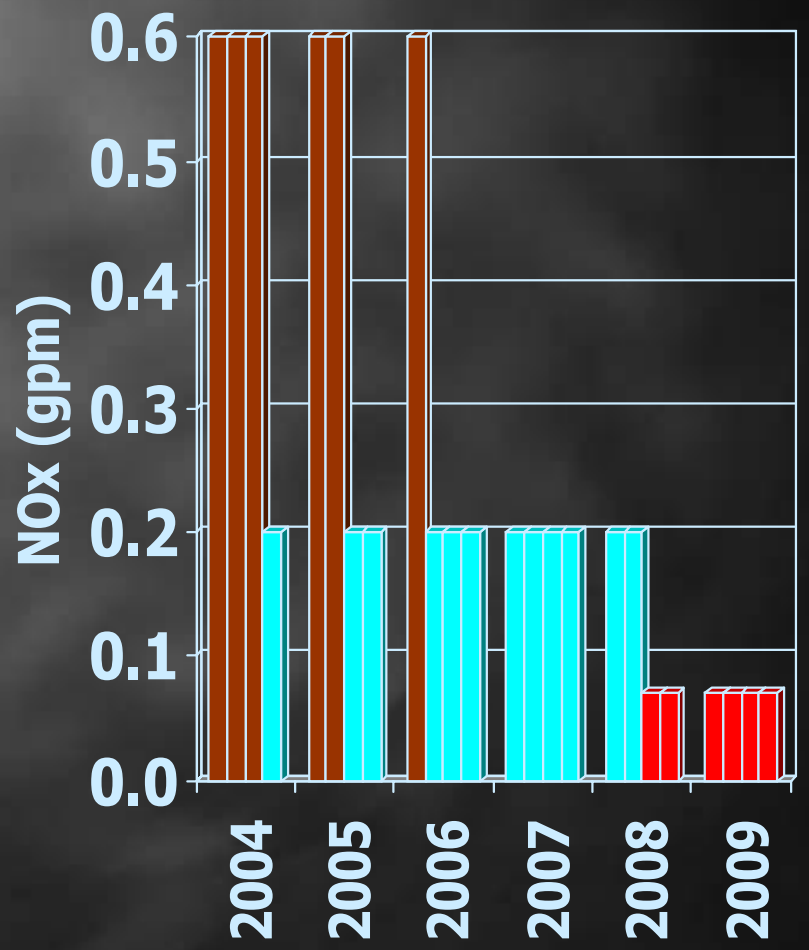
# Phase-In of the Proposed Tier 2 NOx Fleet Averages

Tier 2 Final
Tier 2 Interim
Tier 2 Balance

**Cars, Trucks < 6000 lb GVWR**




**Light Trucks > 6000 lb GVWR**



# Proposed Tier 2: Maximum NOx Levels

Tier 2 Final
Tier 2 Interim

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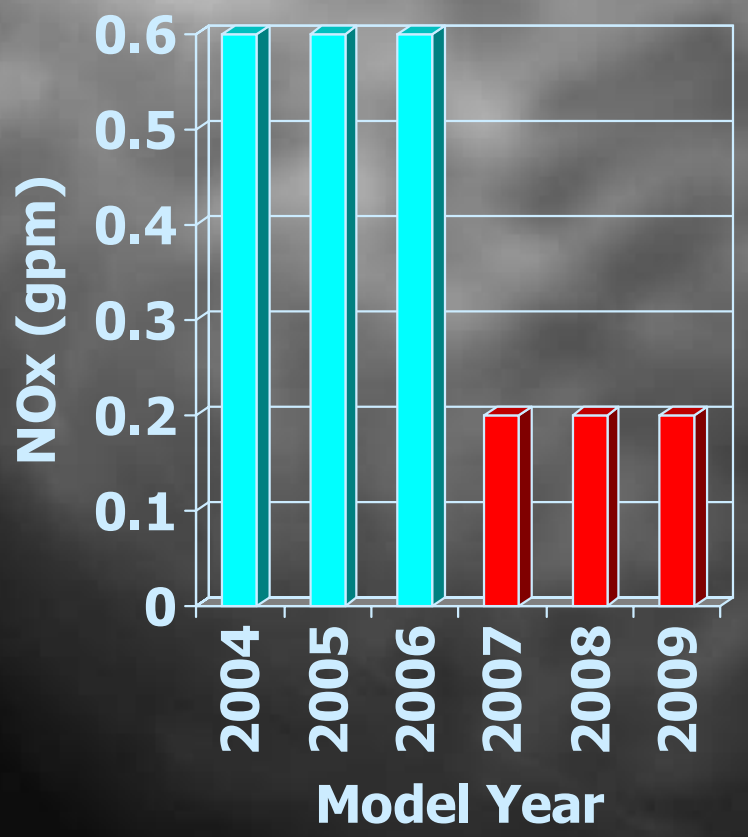


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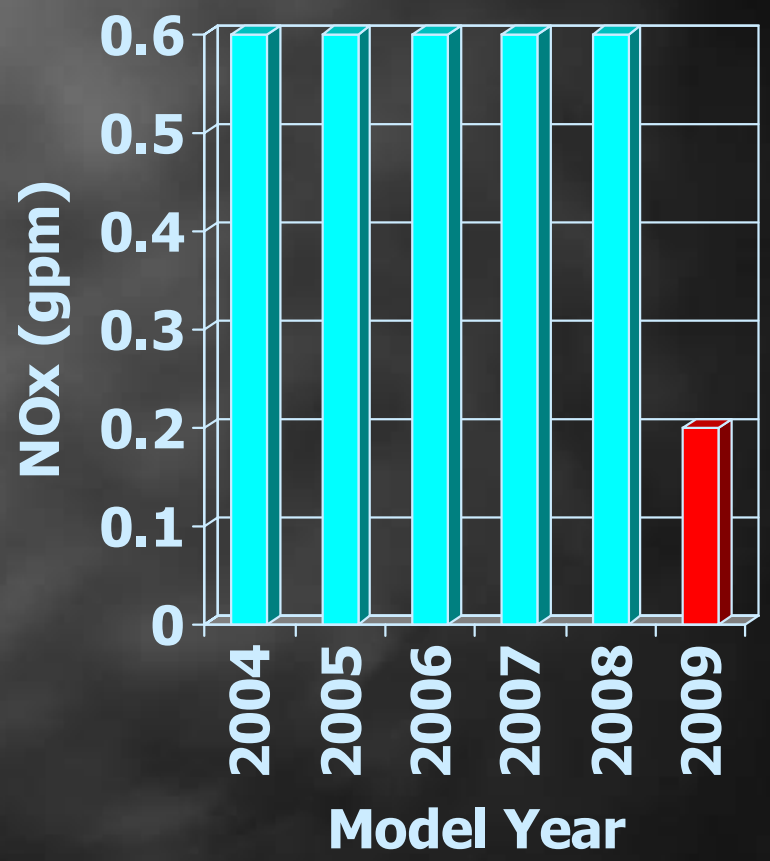
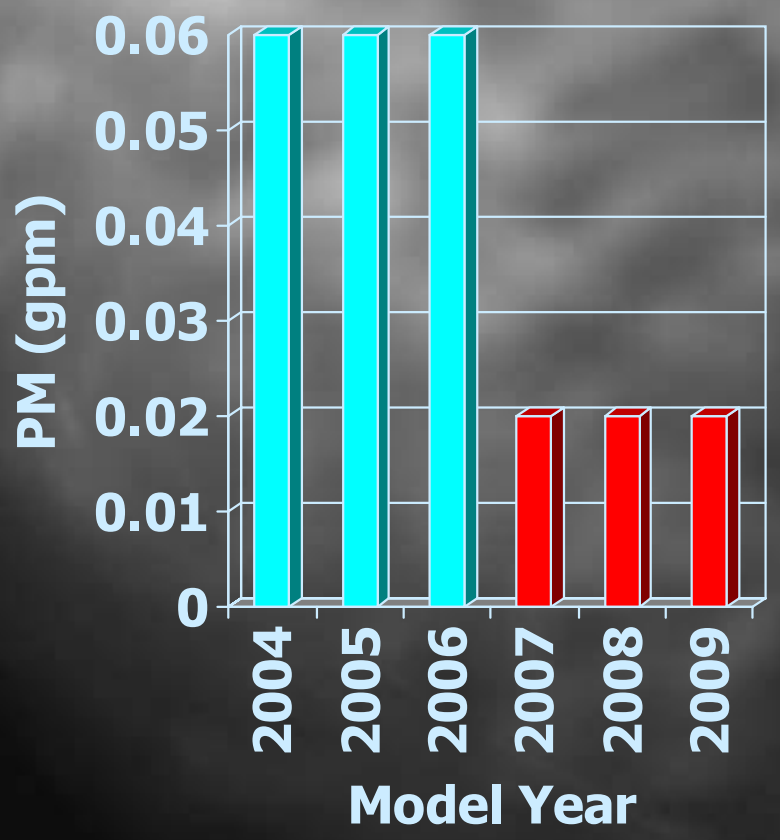


# Proposed Tier 2: Maximum PM Levels

Tier 2 Final
Tier 2 Interim

**Cars, Trucks < 6000 lb GVWR**

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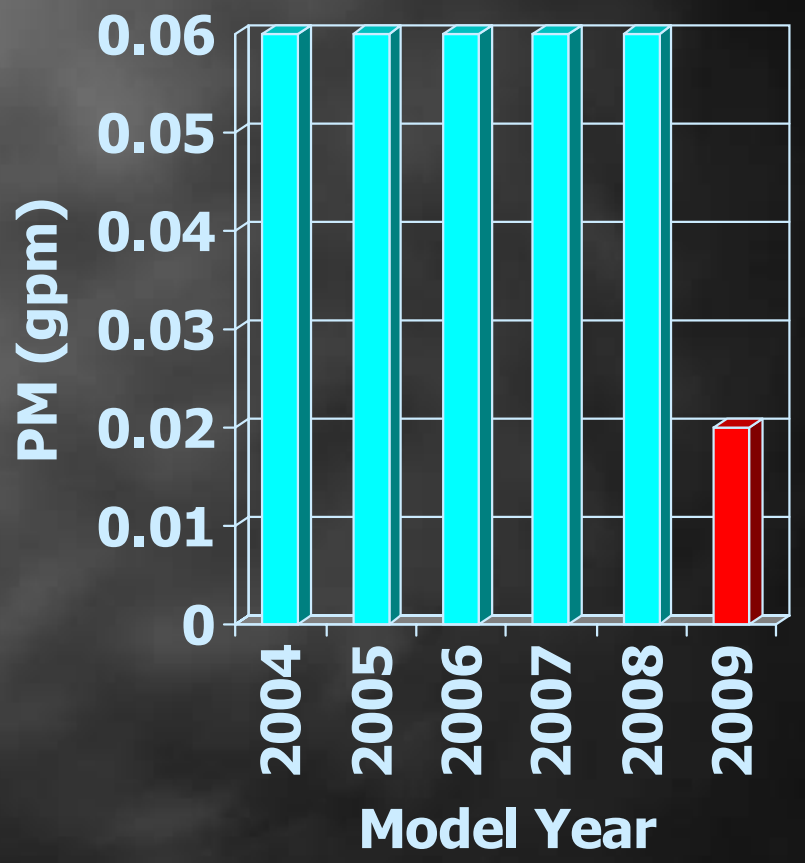
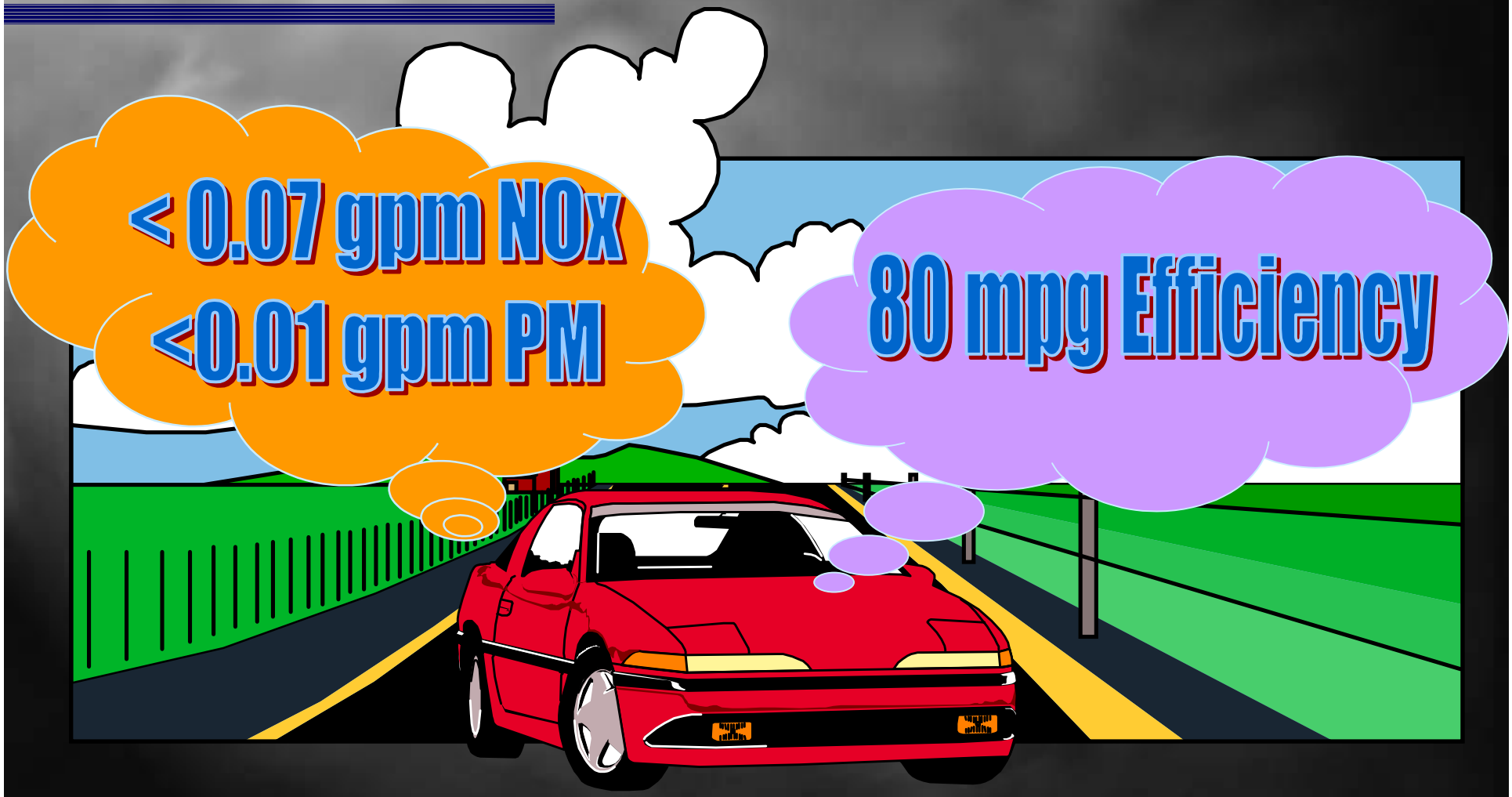


# Ultimately Future Engine Designs Should Help Vehicles Deliver...



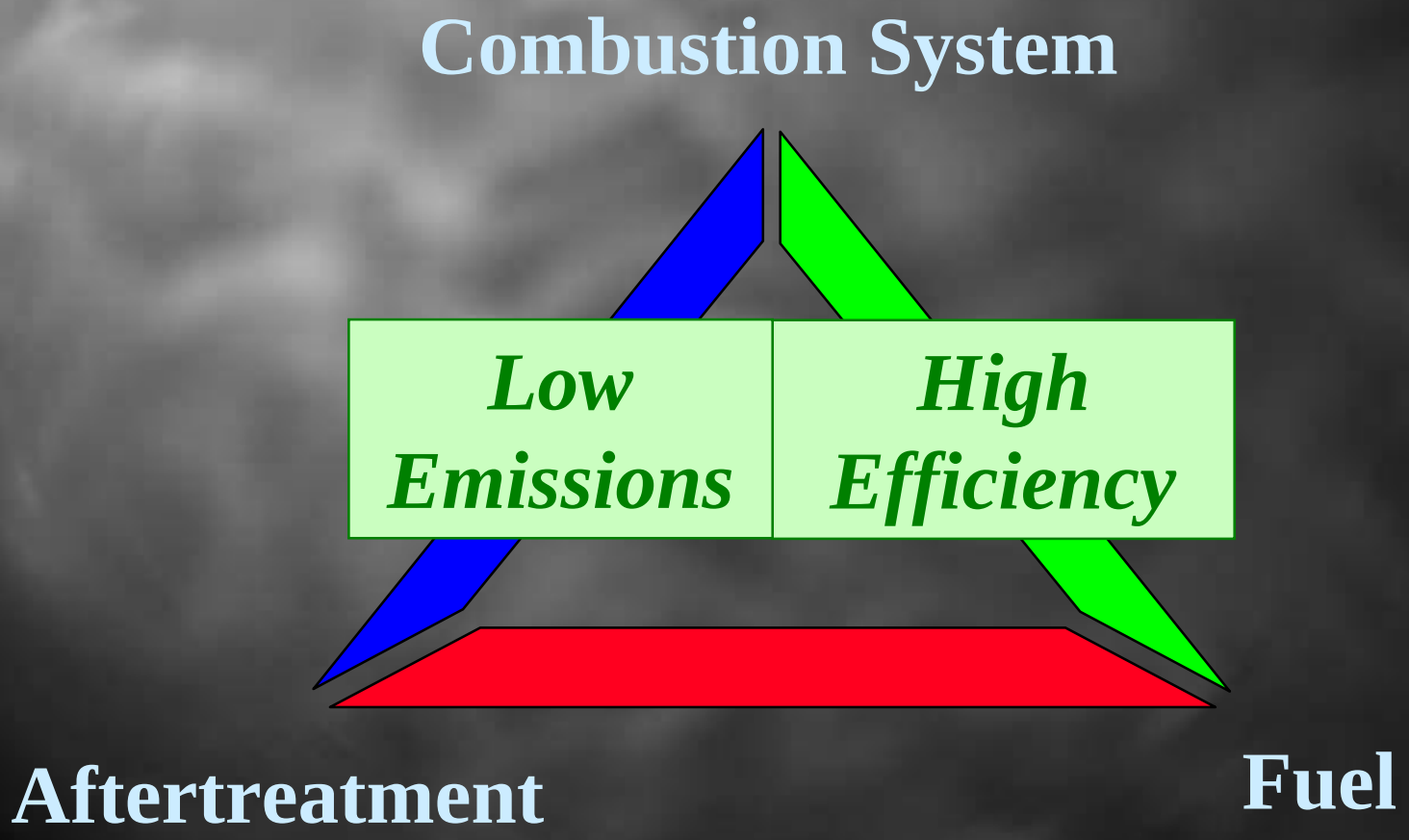
# Engine Equivalent Stringency to Tier 2

| | Tier 2 NOx g/mi | Engine NOx g/bhp-hr | Tier 2 PM g/mi | Engine PM g/bhp-hr |
|---|---|---|---|---|
| Typical Car | .07 | .2 | .01 | .03 |
| Large SUV | .07 | .1 | .01 | .015 |

# HD Engine Goals

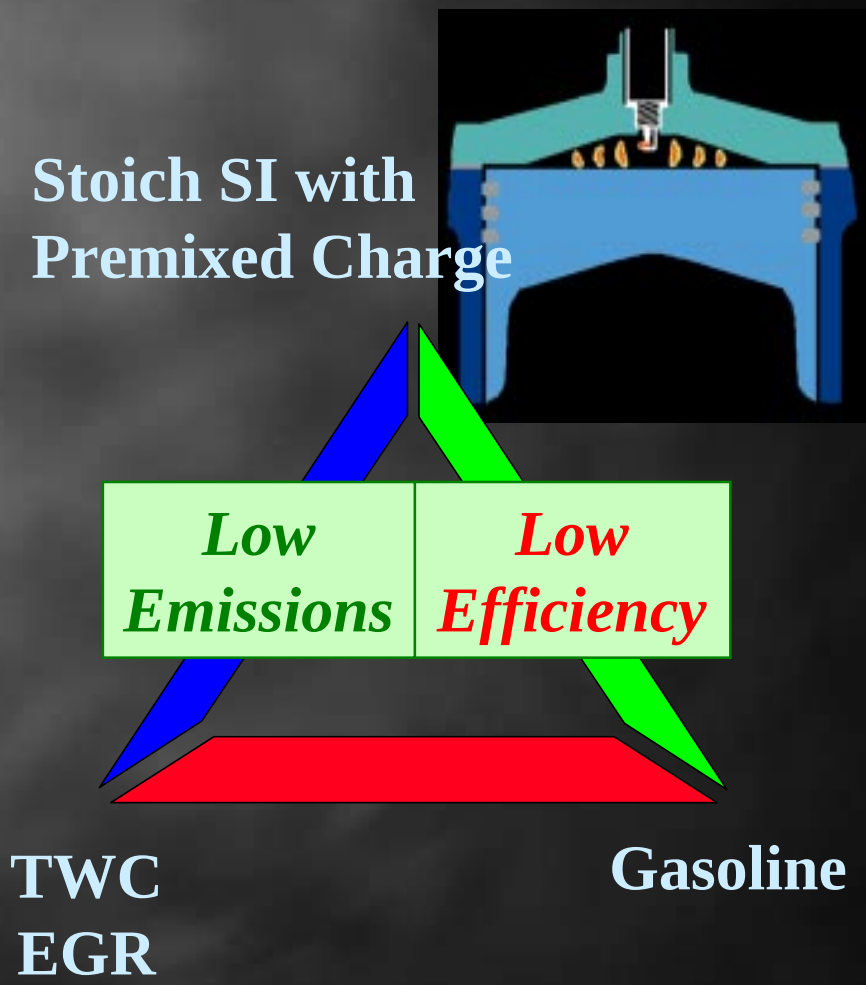
| Year | Engine NOx g/bhp-hr | Engine PM g/bhp-hr |
|---|---|---|
| 2007 - 2008 | 0.5 | .010 - .025 |
| 2010 -2012 | 0.1 | .010 - .020 |

# Research Focus: Achieving Integrated Solutions...



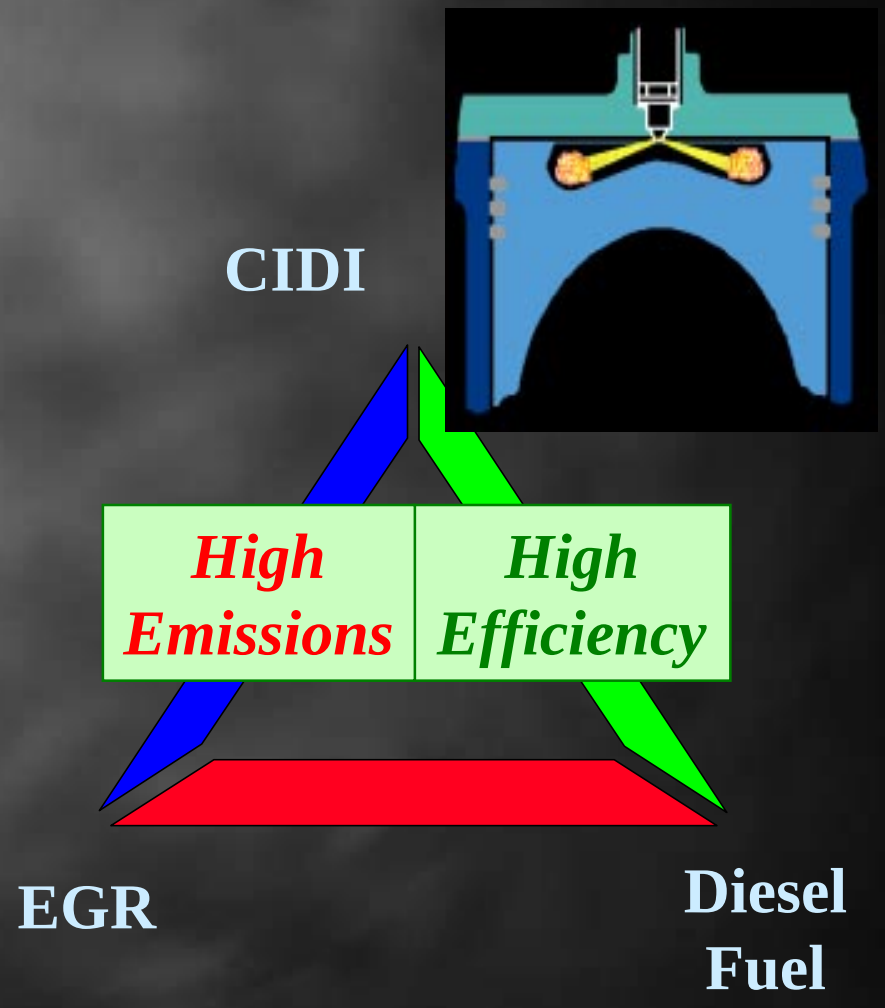
# Conventional SI with Premixed Charge + Gasoline = Low Emissions, *but Inefficient*

- Homogeneous charge, inherently low PM
- High peak temp = high NOx, but stoich operation allows TWC
- *Throttling and low compression ratios reduce efficiency*



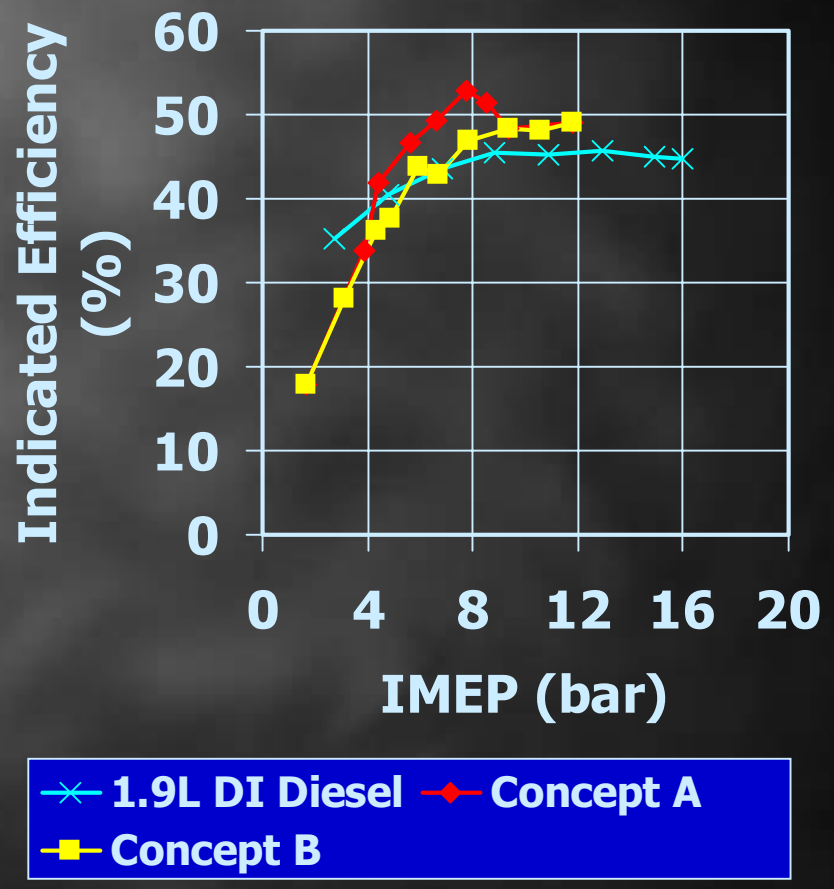
# Conventional CI Direct Injection + Diesel Fuel = Efficient but has *High Emissions*

- High compression & unthrottled = high efficiency…
- *…But stratified charge = high PM*
- *High peak combustion temperatures = high NOx; lean operation prevents use of TWC*

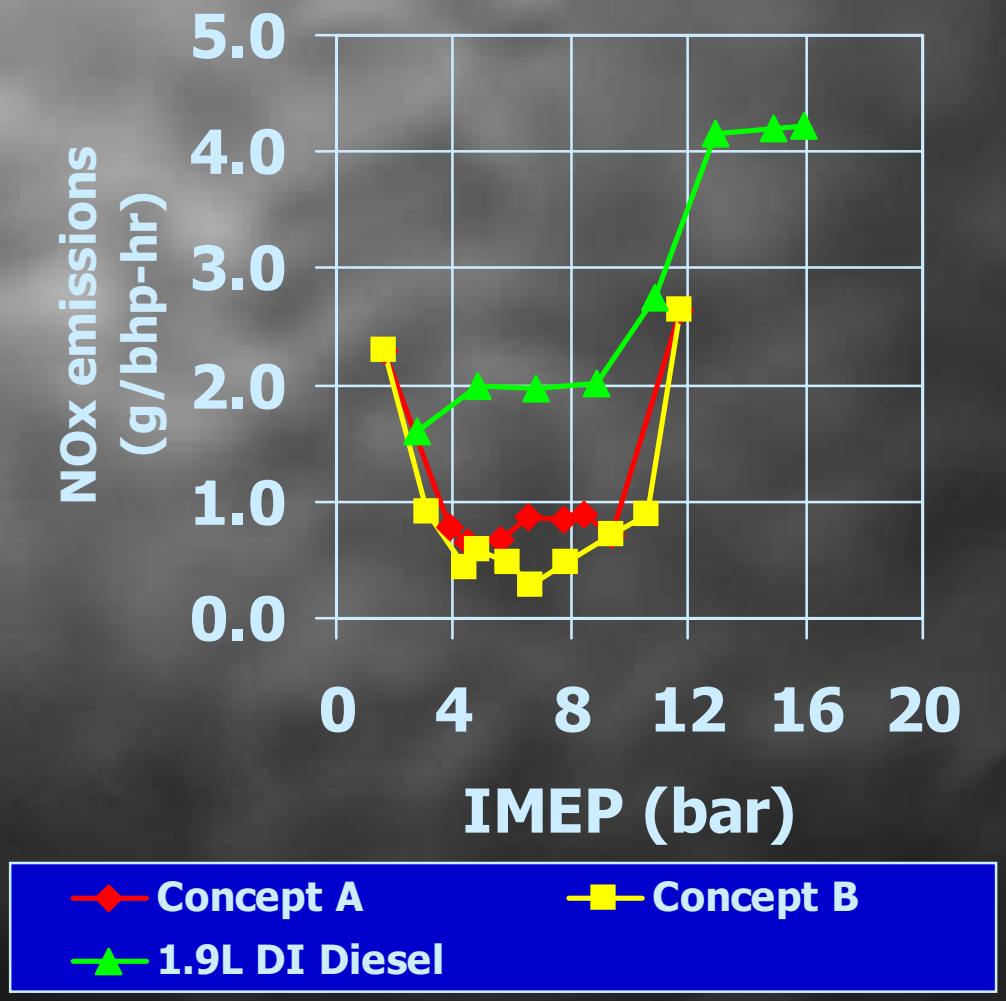


# Alternative Fuel Research Engines Already Clear "High Bar" Efficiencies...

- Renewable alcohol research engine
- Two different combustion concepts
- Efficiencies exceed state-of-the-art diesel



# …While Exhibiting Low Engine-Out NOx



# Approach Employs late DI with Stoichiometry, on Methanol

- Predicted advantage for fuels with no or one carbon bond…
- Implies additional focus: similar concept on EtOH, DME
- *Raises fuel infrastructure issues*

**Late DI, Stoich**

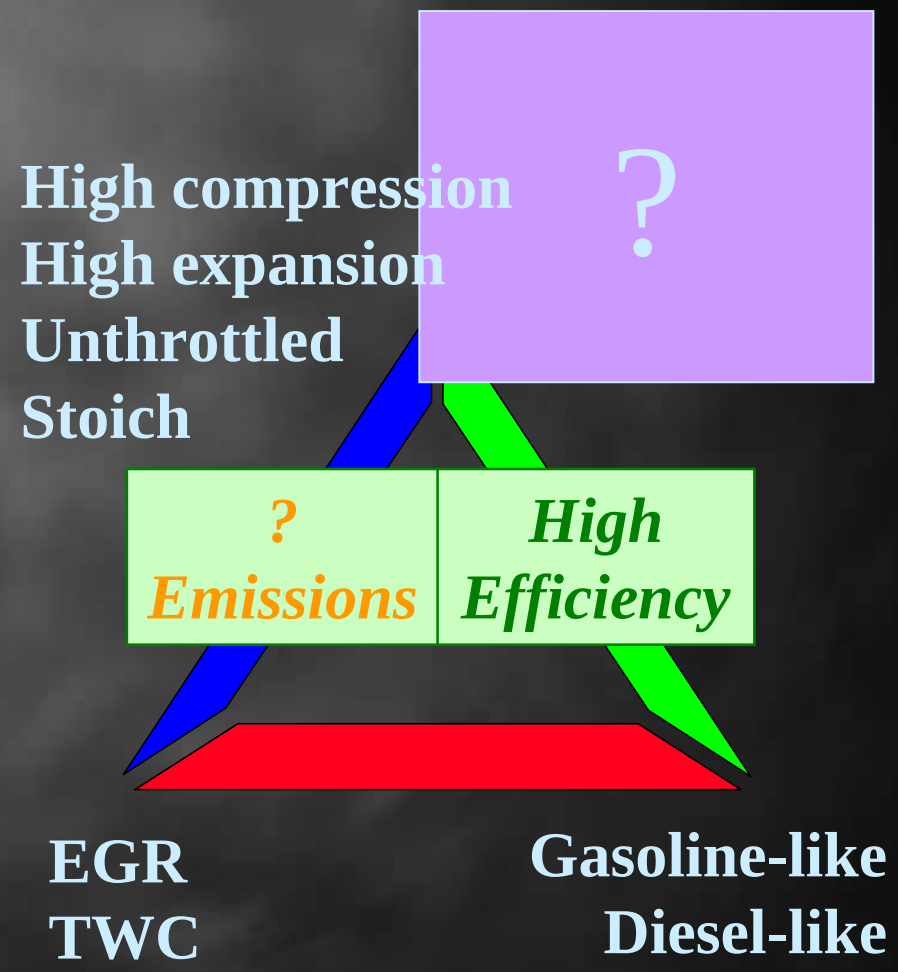
***Low Emissions*** | ***High Efficiency***

**TWC**
**EGR**

**MeOH**
**EtOH?**
**DME?**

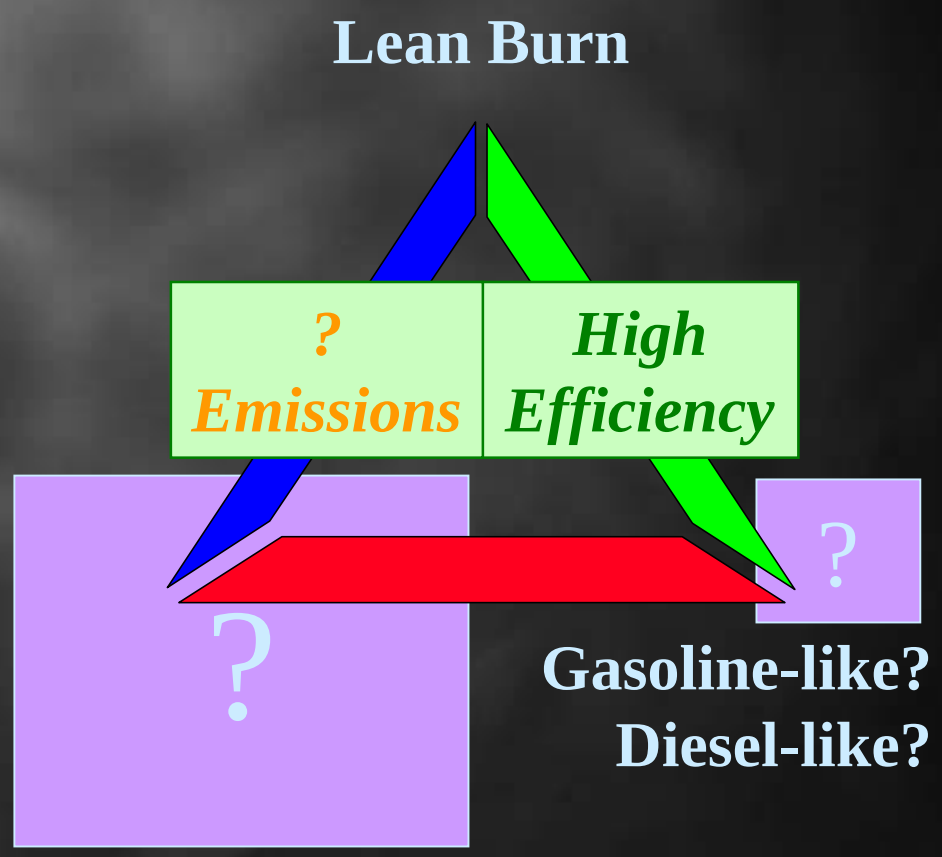
# Research Opportunity: Gasoline/Diesel-Like Fuels at Stoich

- If efficiency is obtained through high compression, high expansion + unthrottled...
- How can the engine be operated at stoich, so as to allow TWC?



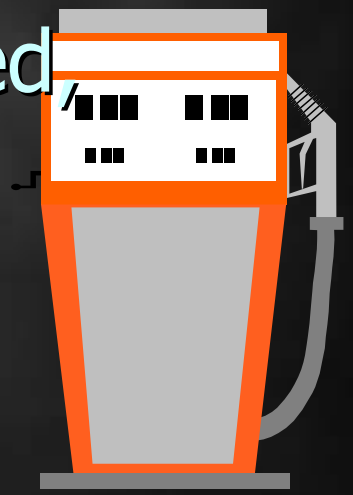
# Research Opportunity: Lean Burn on Gasoline/Diesel-Like Fuels

- If engine is operated with lean burn...
- Need more research on NOx adsorbers, plasma cats, PM traps
- Includes issue of achieving intermittant rich operation to purge adsorber



# New Fuels Enable Advanced Aftertreatment

- Low sulfur
- Somewhat dependent on combustion approaches not yet demonstrated
- NOx/PM traps, SCR, plasma cats
- If separate/segregated fuel required, should we ramp up alt fuel focus now?

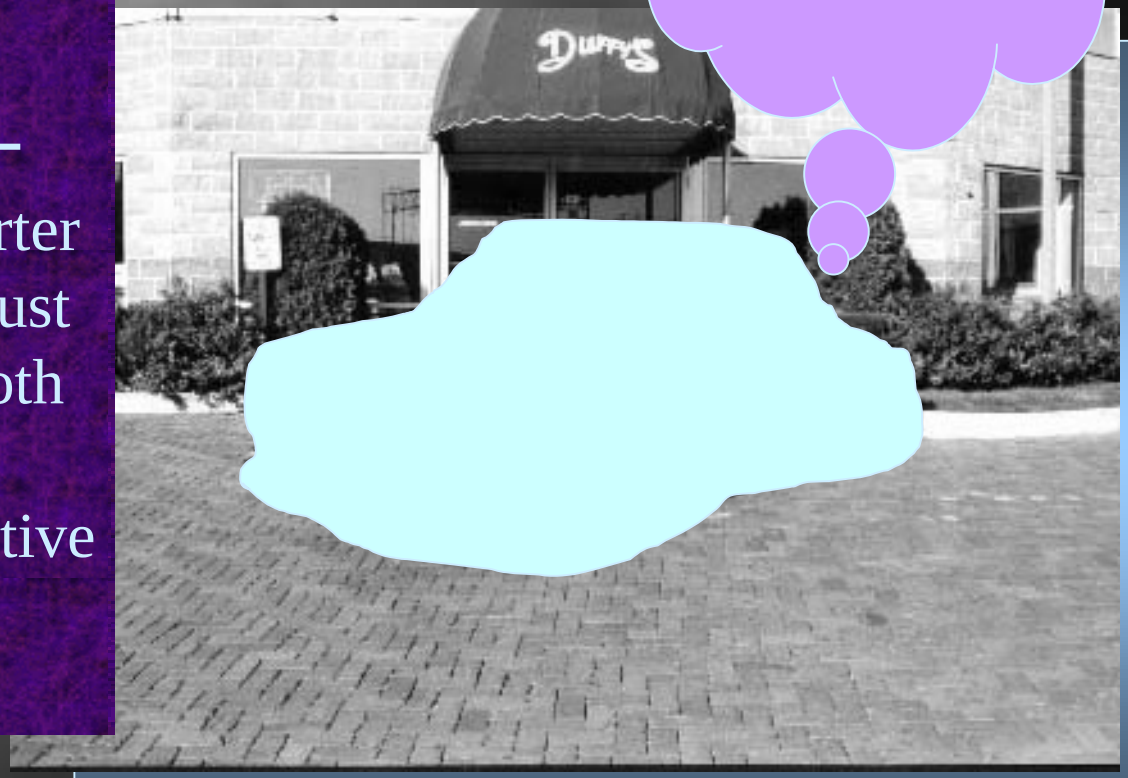


# Future Prospects for Even Higher Efficiency

- Lower heat rejection
- Cost-effective bottoming cycles
  - especially in hybrid applications
  - focus on parallel hybrid w/ load-leveled engine operating in high-load, high efficiency regime

# Twenty Years from Now...

xxx mpg
.00y gpm NOx
.00z PM

**2019 Dream Sedan**

37 CID Fuel Converter
"Magic Aire" Exhaust
Continuously Smooth Transmission
All-Wheel Regenerative Braking