Wood-to-Wheels
Engines and Vehicles Research

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Advanced Power Systems Research Center

Advanced IC Engine Laboratories

APS Center

• **10 Faculty:** Combustion, engines emissions, powertrain design, engines combustion/emissions, controls, modeling, fuel cells, and NVH.

• **30 Graduate Students**

• Related Research Programs:
  - Biodiesel combustion and emissions
  - **Ethanol and Flex-Fuel**
  - Hydrogen & H2/Gasoline ICE
  - Beans-to-Boat
  - Clean Diesel & Aftertreatment
  - Fundamental Combustion
  - ICE Real-time combustion detection and control
  - Flex-fuel diesel

AICE Laboratories

• **7 engine test labs in the ME**

• Chassis Cell in ATDC

• Expanding to the KRC for additional engine programs

• Developing a NSF newly funded alternative fuels combustion laboratory

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Existing Alternative Fuels Research IC Engine

Modified CRF Engine for gasoline – ethanol, NG, and hydrogen combustion research

- Variable compression ratio (4.6 - 17.5)
- Design and fabrication of intake and exhaust manifold
- Electronic Closed Loop EGR
- Port fuel injection – Multi-fuel operation (gasoline-ethanol and hydrogen)
- Intake charging
- Closed loop control of intake air, lambda - fuel quantity and timing, EGR, spark timing and energy, knock, and engine coolant and oil temperature.
Alternative Fuels Combustion Laboratory

NSF Funded Laboratory

- Applications include
  - Clean diesel combustion
  - High boost simulation
  - High EGR dilution
  - SI DI
  - Alt Fuel combustion characteristics
- High speed imaging, laser & optical diagnostics
- High pressure fuel injection
- Wide range of ambient temperatures and pressures
- Flexible gas compositions

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We have Flex-Fuel vehicles today and more are on the way.

- GM has over 2 million Flex-Fuel Vehicles on the road today…

- By 2012, GM in partnership with Daimler-Chrysler and Ford, aim to have half of annual vehicle production be E85 flexible fuel or bio-diesel capable.

What’s needed?
# Ethanol as a Fuel

<table>
<thead>
<tr>
<th>Property</th>
<th>Gasoline</th>
<th>Ethanol</th>
<th>Impact of Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Formula</td>
<td>C4 – C12</td>
<td>C₂H₅OH</td>
<td>Oxygenated fuel</td>
</tr>
<tr>
<td>Composition, Weight % (C, H, O)</td>
<td>(86, 14, 0)</td>
<td>(52, 13, 35)</td>
<td>Slightly lower combustion temp.</td>
</tr>
<tr>
<td>Lower Heating Value (Btu/gal)</td>
<td>115,000</td>
<td>76,000</td>
<td>Reduced MPG</td>
</tr>
<tr>
<td>Octane Number (R+M)/2</td>
<td>86-90</td>
<td>100</td>
<td>Reduced knock, Improved efficiency</td>
</tr>
<tr>
<td>Reid Vapor Pressure (psi)</td>
<td>8-15</td>
<td>2.3</td>
<td>Reduced start-ability</td>
</tr>
<tr>
<td>Latent Heat of Vaporization (Btu/gal)</td>
<td>150</td>
<td>396</td>
<td>Increased charge cooling, Reduced start-ability</td>
</tr>
<tr>
<td>Volume % fuel in Stoich Mixture</td>
<td>2</td>
<td>6.5</td>
<td>Requires increased fuel vaporization &amp; mixing</td>
</tr>
<tr>
<td>Stoich air/fuel (weight)</td>
<td>14.7</td>
<td>9</td>
<td>Requires increased fuel vaporization &amp; mixing</td>
</tr>
<tr>
<td>Laminar Flame Speed (cm/s)²</td>
<td>27</td>
<td>42</td>
<td>Increased thermal efficiency, Increased EGR tolerance</td>
</tr>
</tbody>
</table>
Ethanol is a better SI engine fuel than gasoline from a combustion standpoint.

Significant challenges in fuel preparation for E100. E85 helps but doesn’t eliminate the problem.

Engine & fuel system should change for ethanol.
The Potential of Ethanol

Comparison of engine efficiency for different fuel types and compression ratios:

- **Gasoline**
- **Diesel**
- **Flex Fuel (E00, E100)**
- **Optimized DI SI Flex Fuel**

Current Technology Flex-Fuel Vehicles

<table>
<thead>
<tr>
<th>Compression Ratio</th>
<th>Indicated Engine Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>25</td>
</tr>
<tr>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>50</td>
</tr>
<tr>
<td>14</td>
<td>60</td>
</tr>
<tr>
<td>16</td>
<td>70</td>
</tr>
<tr>
<td>18</td>
<td>80</td>
</tr>
<tr>
<td>20</td>
<td>90</td>
</tr>
<tr>
<td>22</td>
<td>100</td>
</tr>
</tbody>
</table>

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EPA has demonstrated a 20% improvement with E85, high CR and EGR.

MIT has estimated 30% improvement with DI SI Gasoline/Ethanol, turbocharging & downsizing.

An E85/E100 optimized SI engines should be as efficient as diesels:
- Lower engine cost
- Lower toxic emissions
Biofuels and Engines

Biomass replacement of US petroleum consumption

1 Billion Tons of Biomass
Bio 30%
Engines & Vehicles Opt

Bio+ICE Opt 39%

Flex-Fuel Hybrid

2005 US Petroleum Consumption (Millions of Barrels)

<table>
<thead>
<tr>
<th></th>
<th>Potential Bio Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Persian Gulf Imports</td>
<td>8,000</td>
</tr>
<tr>
<td>Biomass</td>
<td>6,000</td>
</tr>
<tr>
<td>Bio+ICE Opt</td>
<td>4,000</td>
</tr>
</tbody>
</table>

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A Technology Solution for Flex-Fuel Hybrids is Required

- Current flex-fuel vehicles do not meet PZEV standards because of crank-start HC emissions.
- Hybrid applications amplify the problem because of increased start-stop cycles.
- Legislation requires hybrids to meet the PZEV standard.

- **Technical solution required for PZEV Flex-Fuel Hybrid**

  The company that develops a robust cost effective solution will have a market advantage.

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*US Emissions Standards*

- **TIER 0** (1981-93)
- **TIER 0** (1994-97)
- **TIER II LEV** (2004 -)
- **TIER I LEV** (1997-03)
- **TIER II SULEV** (2004 -)
- **TIER II PZEV** (2004 -)

* Standards in g/mi converted to g/km
MTU’s Ethanol Research Program with GM:
Flex-Fuel DI-SI Engine Optimization for Hybrid Application
Phase 1 – GM/MTU Program Goal and Objectives

Goal: Develop Ethanol-Hybrid powertrains that meet PZEV emissions standards.

Objectives: Investigate and develop technologies that
- Improve engine efficiencies
- Reduce HC emissions to PZEV level
- Eliminate start-stop-start issues to enable an ethanol-hybrid
- Improve design capability by developing ethanol engine simulation capability
GM / MTU DI-SI Flex-Fuel Engine

Single Cylinder Research Engine Platform

Design and Fabrication Complete May 2006

Continuously Variable Intake & Exhaust VCT

GM Advanced DI SI Fueling & Combustion System
The GM/MTU DI-SI Engine will provide an exceptional research platform for Flex-Fuel optimization and emissions reduction.

- Multiple piston designs and compression ratios
- Multiple CAM’s
- MTU developed controls
- Combustion Optimization
- Crank-Start Emissions Reduction
- Data for Engine Simulation
Variable CR / Displacement

What Next?
Fuel/Engine Database
Predictive Engine and Combustion Model

Improved/Low Cost Feedback Combustion and Knock Control

Downsized Flex-Fuel ICE

Fuel System Characterization

Collaboration Partners
SC Injection System for Cold-start

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Downsized Flex-Fuel ICE