Thermoelectric Opportunities for Light-Duty Vehicles

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Agenda

• Ford’s Sustainability Strategy
• Regulatory and Societal Motivations for Energy Efficiency
• The Changing Landscape of Vehicle Technologies
• The Role of Waste Energy Recovery On-Vehicle
• Enabling Strategies for Thermoelectrics HVAC
• Summary
A Broad Approach to Sustainable Transportation

- **Sustainable Governance:**
  - Ethical business practices
  - Addressing global public policy issues (Environmental & Safety Regulations)
  - Incorporation of sustainable raw materials in product and manufacturing

- **Economic Sustainability:**
  - Operate profitably at current demand and changing model mix
  - Develop new products our customers want and value
  - Finance our plan and improve our balance sheet
  - Work together effectively as one global team

- **Environmental Sustainability:**
  - Climate Change / GHG Emissions / Fuel Economy
    - Each new or significantly refreshed vehicle will be best in class, or among the best in class, for fuel economy
    - Reduction in facility CO2 emissions of 30 percent by 2025 on a per-vehicle basis
  - Water Use / Waste Disposal / Supply Chain Environmental Sustainability

- **Societal Sustainability:**
  - Employees: Workplace Health & Safety, Working-Together
  - Customers & Communities: Fuel Economy, Safety, Connected Life, Volunteer Corps
  - Dealers/Suppliers
  - Investors

** Ford’s 2010/11 Sustainability Report is online at: http://corporate.ford.com/microsites/sustainability-report-2010-11/default
## Sustainability Strategy – Technology Migration

### Near Term
- Begin migration to advanced technology
- Significant number of vehicles with EcoBoost engines
- Electric power steering – begin global migration
- Dual clutch and 6 speed transmissions replace 4 & 5 speeds
- Flex Fuel Vehicles
- Add Hybrid applications
- Increased unibody applications
- Introduction of additional small vehicles
- Battery management systems – begin global migration
- Aero improvements
- Stop/Start systems (micro hybrids) introduced
- CNG/LPG Prep Engines available where select markets demand

### Mid Term
- Full implementation of known technology
- EcoBoost engines available in nearly all vehicles
- Electric power steering - High volume
- Six speed transmissions - High volume
- Weight reduction of 250 – 750 lbs
- Engine displacement reduction aligned with weight save
- Additional Aero improvements
- Increased use of Hybrids
- Introduction of PHEV and BEV
- Vehicle capability to fully leverage available renewable fuels
- Diesel use as market demands
- Increased application of Stop/Start

### Long Term
- Continue leverage of Hybrid technologies and deployment of alternative energy sources
- Percentage of internal combustion engines dependent on renewable fuels
- Volume expansion of Hybrid technologies
- Continued leverage of PHEV, BEV
- Introduction of fuel cell vehicles
- Clean electric / hydrogen fuels
- Continued weight reduction actions via advanced materials
- Introduction of new technologies that enable broad sustainability plan

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**Research & Advanced Engineering**

3rd Thermoelectrics Applications Workshop
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Baltimore, MD
Hybrids, Plug-in Hybrids, and BEVs
Regulatory & Societal Motivations to Develop Energy Efficient Vehicle Technology

- Fuel economy trends driven by global factors:
  - US and California
  - EU CO\textsubscript{2} Regulations
  - Global Oil Prices
- Fuel prices will continue to be put under pressure by increasing demand from emerging markets
- Fuel economy targets in emerging markets are lagging developed countries only by a few years
- By 2030, car ownership in China is expected to reach 230M units
- Safety & emissions regulations in emerging markets are lagging developed countries only by a few years

“We are committed to being a leader in fuel economy in every product segment in which we compete. In keeping with our heritage as a company, we introduce new technology on a large scale.”
- William Clay Ford Jr., June 2010

Competition for the Almighty Dollar

- Passive Safety (after the crash)
- Active Safety (avoiding the crash)
- Emissions (NOx, PM, CO, HC, etc.)
- Feature Content (you can never have enough cup holders!)
- Fuel Economy Technology
The Changing Landscape of Vehicle Technologies

- Multiple technologies are under consideration:
  - Improve regulated fuel economy / safety
  - Attract consumers through marketable features

- Winners determined by total competitiveness in areas of:
  - Performance (W/kg, W/m³, W-hr/kg, W-hr/m³, W/$)
  - Cost (enable cost avoidance, $/mpg saved, etc.)
  - Robustness / Quality (250K, 15 year durability)
  - Ease of migration across fleet (B-car, Full-size truck, gas, diesel)
  - Ease of integration (migration ability, partnerships with T1)
  - Marketable feature (OEM revenue opportunity and differentiation)
  - Secondary benefits (Improve driver seat comfort, reduce cabin noise)

To be competitive in the auto industry, technology must be mature and adaptable to a changing market.
Technology Trends for Improving FE

Avg $ / 1% FC Improvement


Cost will contribute significantly to technologies implemented for fuel economy improvement
The Role of Waste Energy Recovery

- Opportunities to Harvest Waste Energy
  - Heat Losses
    - Engine Exhaust
    - Engine Fluids
    - Braking
    - Electronics
    - Solar Load
  - Mechanical Losses
    - Pumping
    - Vibrations
    - Driveline (crankshaft to wheels)
    - Braking / Steering
  - Aerodynamic losses
    - Frontal area
    - Coefficient of drag

- Opportunities to Use Waste Energy
  - Offload electrical load
  - Offload mechanical load
  - Provide/transfer heat (coolant, oil, battery, …)
  - Store thermal energy
  - Store electrical energy (battery, capacitor, …)
  - Store mechanical energy (spring, hydraulic, flywheel, …)
Harvesting Engine Exhaust using Thermoelectric Power Generation

Thermoelectric Generator Installed Mid-Body
TEG Performance for a 65mph Freeway Cruise
Challenges for Alternator Replacement by a TEG

- **TEG must be able to provide necessary power to the vehicle under extremely challenging conditions:**
  - Provide 220 Amps @ 14 Volts (3kW) under worse-case electrical load conditions
  - Vehicle Idle
  - City drive cycle (Start-Stop)
  - +50°C to -30°C ambient conditions
  - Full accessory loads, including current spikes
  - Reduce TOTAL fuel consumption, weight, and cost compared to an alternator/battery system

- **Ability to replace alternator in conventional vehicles is challenging**

- **Potential to supplement alternator is more attractive**

- **Significant potential for power generation in vehicles during highway cruise**

- **EPA and EU off-cycle credits / EcoInnovation credits offer incentive to OEMs to adapt TEG designs for real-world operation**
Objective: Provide occupant comfort over a broad range of ambient conditions

- HVAC functions include:
  - Occupant cooling (-40°C) and heating (+50°C)
  - Dehumidifying, defogging, & defrosting

Considerations for a TED:
- Location, air flow rate, and temperature of localized air streams
  - Directly affect occupant comfort
  - Optimized for both heating and cooling modes
- Control strategy is critical to HVAC system performance and energy consumption
  - Best effective use of TED for zonal design may be to complement the main HVAC system
- Input power and voltage to TED
  - Limited available 12-volt power, even on HEVs
- Liquid-to-air or liquid-to-liquid devices
  - Improved efficiency but added mass and complexity
- Thermal mass of system
- Total system costs

Motivation: HVAC is the largest single non-motive consumer of power in a vehicle
## Typical Cabin Thermal Conditions

<table>
<thead>
<tr>
<th>HVAC Mode</th>
<th>Average Interior Temperature</th>
<th>Breath Temperature</th>
<th>Floor Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/C</td>
<td>20 – 30°C</td>
<td>20 – 25°C</td>
<td>22 – 35°C</td>
</tr>
<tr>
<td>Heating</td>
<td>22 - 30°C</td>
<td>15 – 25°C</td>
<td>27 – 37°C</td>
</tr>
</tbody>
</table>
Model-based design allows for flexibility in analyzing key parameters.
Subjective and Objective Validation of Thermal Comfort

Typical results: -5°C Ambient Test

Objective and subjective analysis of HVAC system performance is still needed for complex, transient systems
Summary

- Ford is committed to improving the efficiency of our vehicle fleet while balancing the needs to provide the value, reliability, safety, and feature content consumers have come to expect.

- Technologies that reduce fuel consumption should be broadly applicable to a global platform strategy and create a perceptible value for the consumer.

- Improvements in powertrain efficiency through waste heat recovery are still extremely challenging. However, they are more viable than ever before due to regulatory motivation and high fuel prices.

- Reductions in HVAC system power consumption, while maintaining or improving occupant thermal comfort, are critical enablers for broad acceptance of electrified vehicles.
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Thank You