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 CO_2 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

2007 | 2011 | 2020 | 2030

Near Term
Begin migration to advanced technology

Mid Term
Full implementation of known technology

Long Term
Continue leverage of Hybrid technologies and deployment of alternative energy sources

Near Term

- ✓ 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

id Term

- 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

- 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

Hybrids, Plug-In Hybrids, and BEVs

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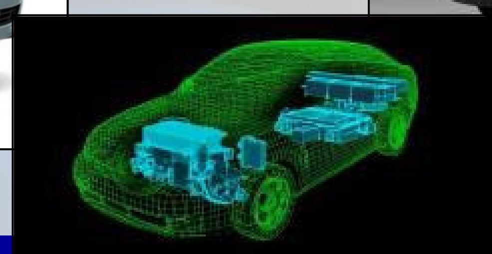


Regulatory & Societal Motivations to Develop Energy Efficient Vehicle Technology

- Fuel economy trends driven by global factors:
  - US and California
  - EU CO_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

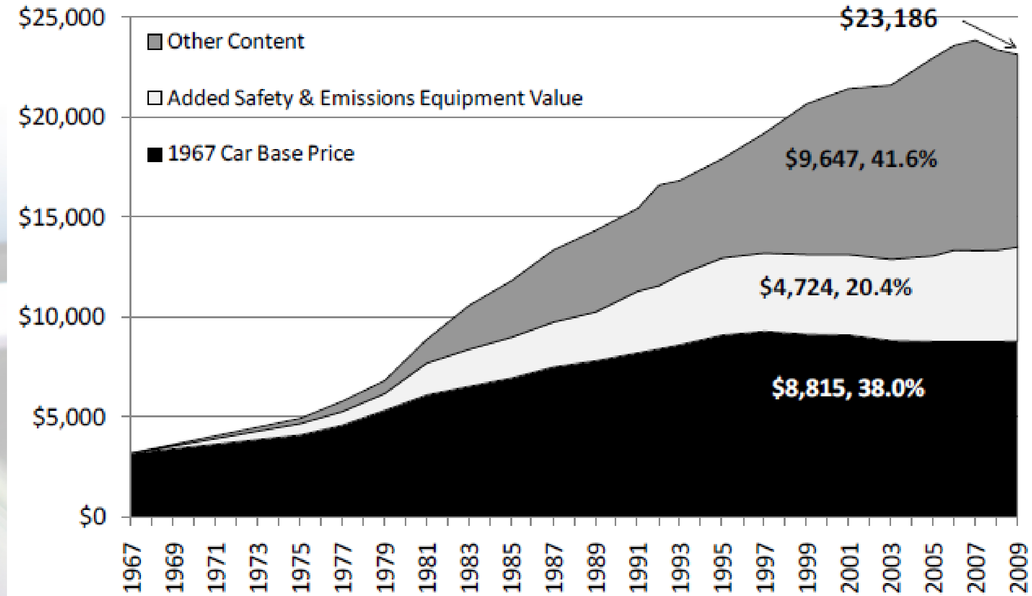
* http://corporate.ford.com/microsites/sustainability-report-2010-11/default

Competition for the Almighty Dollar

SAFETY AND ENVIRONMENTAL REGULATORY CHANGES UNDER CONSIDERATION

Issue Area	Anticipated Next Action
KT Safety Act Implementation	
Rearward Field of View	NPRM – Nov. 2010
Power Window Safety	Final Rule – Apr. 2011
Driver Distraction Plan – Voluntary Guidelines	
Visual-Manual – IEM Integrated Devices	Q3 – 2011
Visual-Manual – Portable Devices	Q3 – 2013
Voice Interfaces	Q1 – 2014
Crash Avoidance Technologies	
Forward Collision Warning (FCW)	Agency Decision – 2011
Lane Departure Warning (LDW)	Agency Decision – 2011
Blind Spot Detection (BSD)	Agency Decision – 2013
Vehicle Communications – V2V/V21	Agency Decision – 2013
Other	
Advanced Automatic Crash Notification (AACN)	Agency Decision – 2010
Compatibility	Agency Decision – 2010
Next Generation NCAP	Multiple Decisions - 2010˜12
Pre-cash Airbag/Safety System Activation	Agency Decision – 2010
"Quieter" Cars	Agency Decision – 2010
Restraint Effectiveness in Rollover	Agency Decision – 2010
Ejection Mitigation	Final Rule – Jan. 2011
Oblique/Low-Offset Frontal Crash	Agency Decision – 2011
LATCH	Agency Decision – 2011
Seat Belt Reminder Systems	Agency Decision – 2011
Light Vehicle EDR Update	Agency Decision – 2012
Low Delta-V Restraint Protection	Agency Decision – 2012
Global Technical Regulations (GTRs)	
Pedestrian Protection	NPRM - 2010
Head Restraints – Phase 1	NPRM - 2010
Glazing	Final Rule – 2011
"Quieter" Cars	Draft Regulation – Feb. 2012
Head Restraints – Phase 2	Agency Decision – 2013

Source: Alliance of Automobile Manufacturers, Comments of the Alliance of Automobile Manufacturers On Notice of Intent for 2017 and Later Year Light Duty Vehicle GHG Emissions and CAFE and Interim Joint Technical Assessment Report, Docket ID Numbers: EPA-HQ-OAR-0799, NHTSA-2010-0131, October 29, 2010, page 9.



Source: Average Expenditure per New Car, Wards' Automotive Yearbook 2010, page 260.

- 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

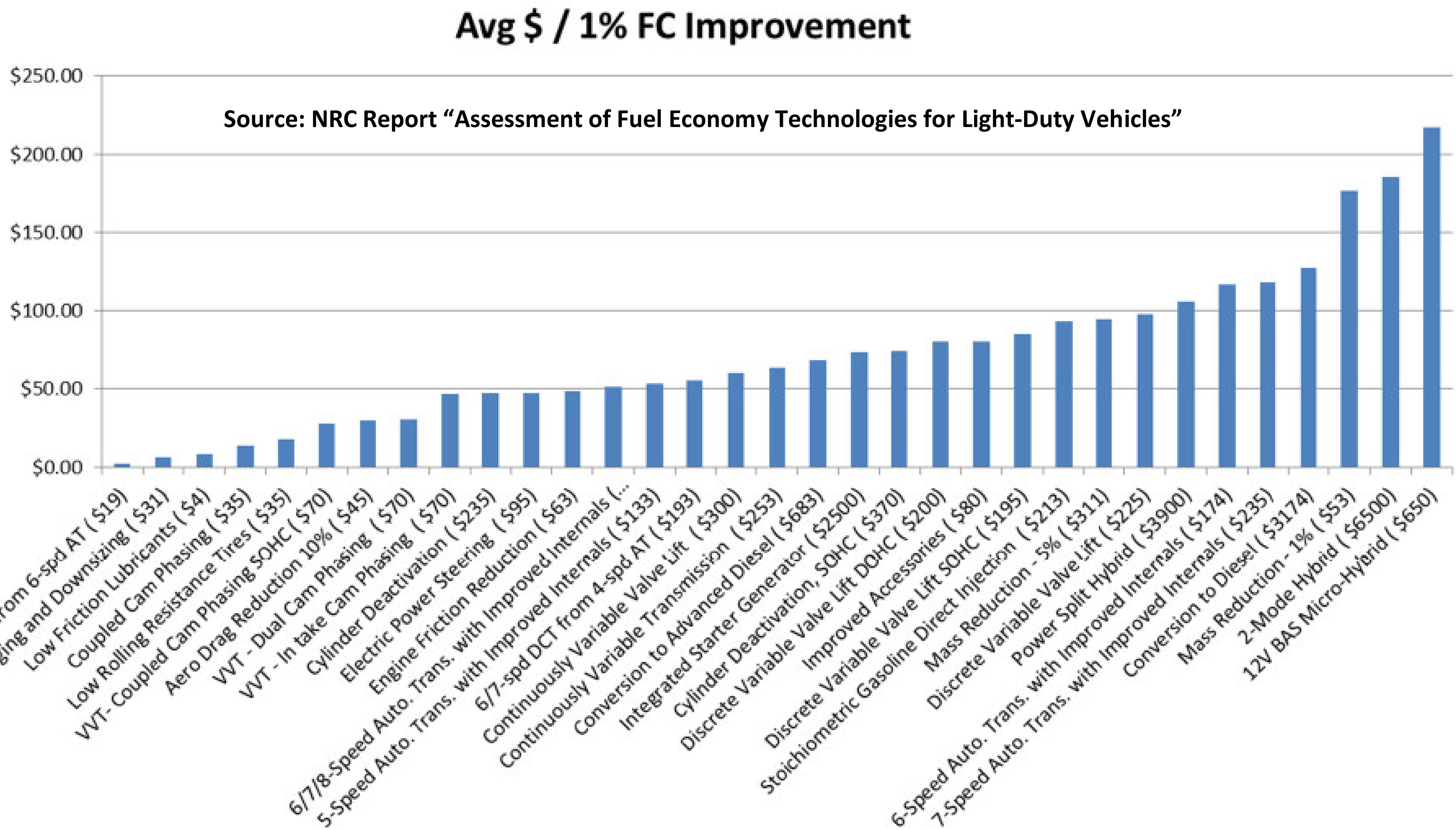
The Changing Landscape of Vehicle Technologies

- 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/m^3, W-hr/kg , W-hr/m^3, 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**

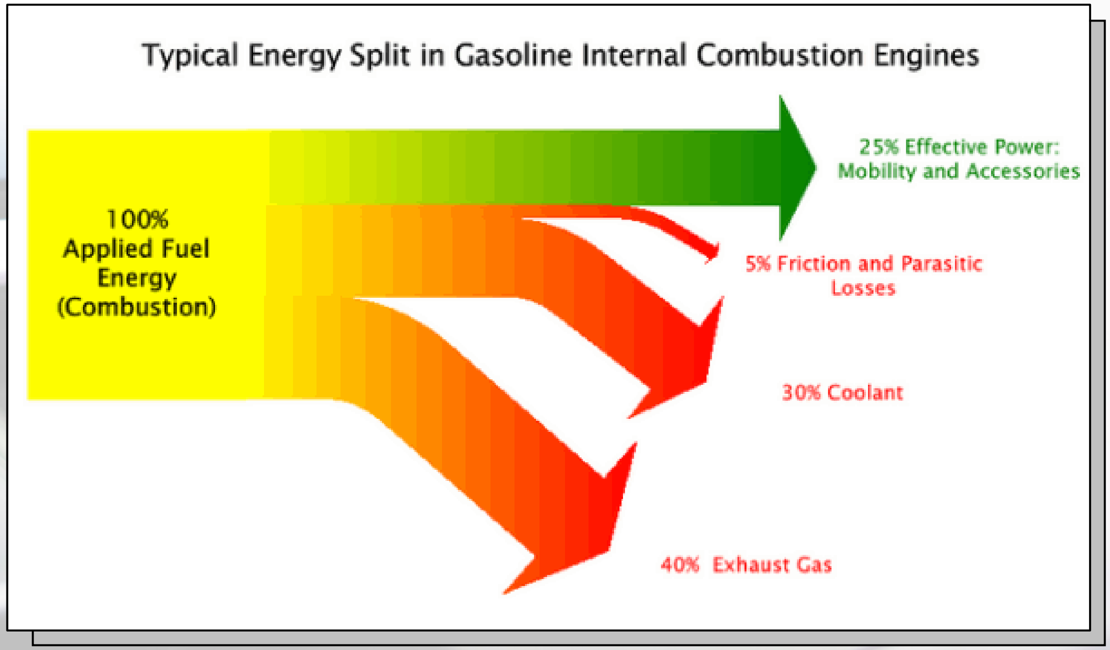
Technology Trends for Improving FE



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

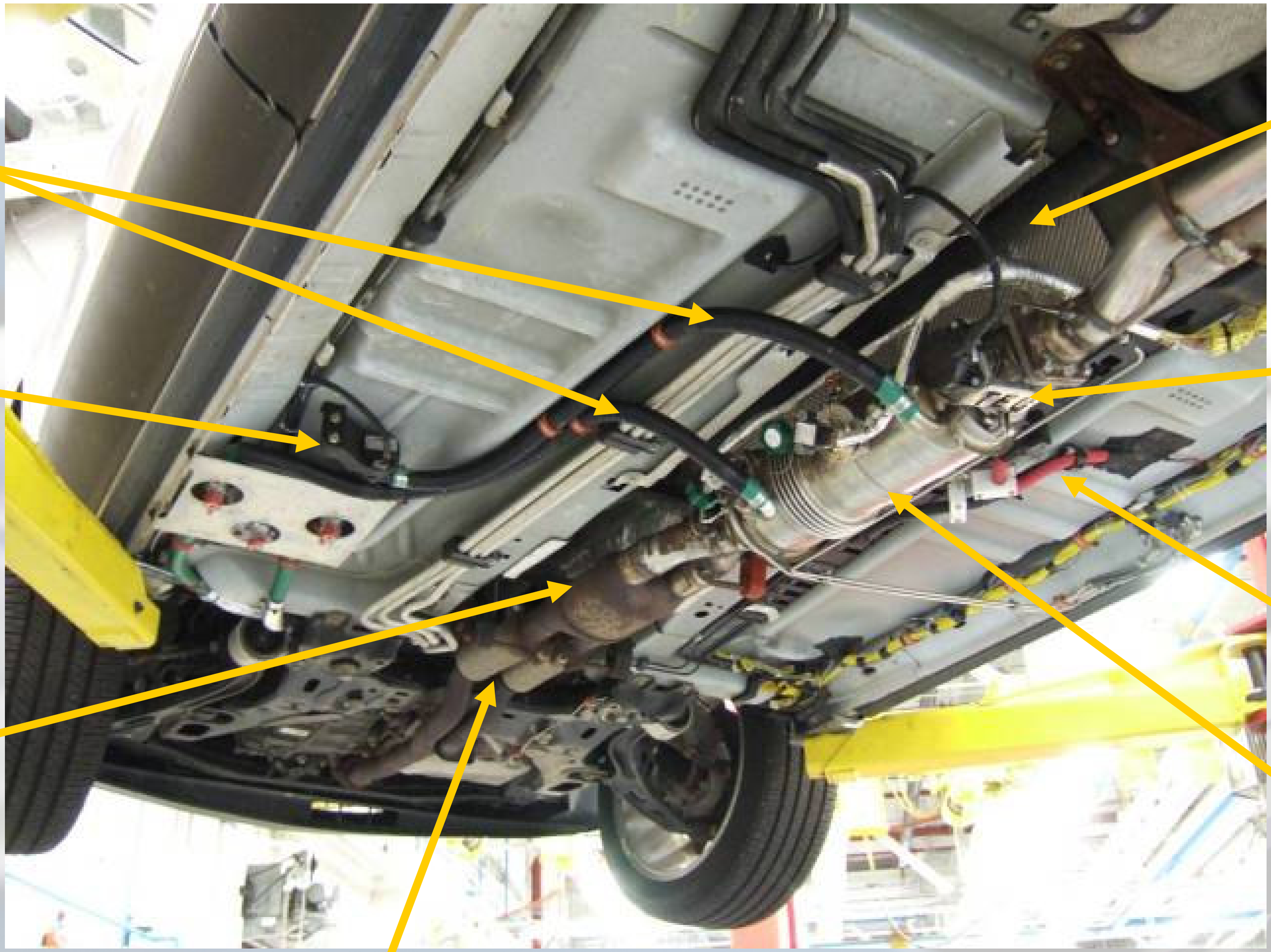


- Opportunities to Use Waste Energy
  - Offload electrical load
  - Offload mechanical load
  - Provide/transfer heat (coolant, oil, battery, …)
  - Store thermal energy
  - Store electrical energy (battery, capacitor, …)
  - Store mechanical energy (spring, hydraulic, flywheel, …)

Harvesting Engine Exhaust using Thermoelectric Power Generation

Thermoelectric Generator Installed Mid-Body

TEG & Exhaust System Packaging



Coolant Lines

Electric Pump

Underfloor Catalyst

Flex Couplings

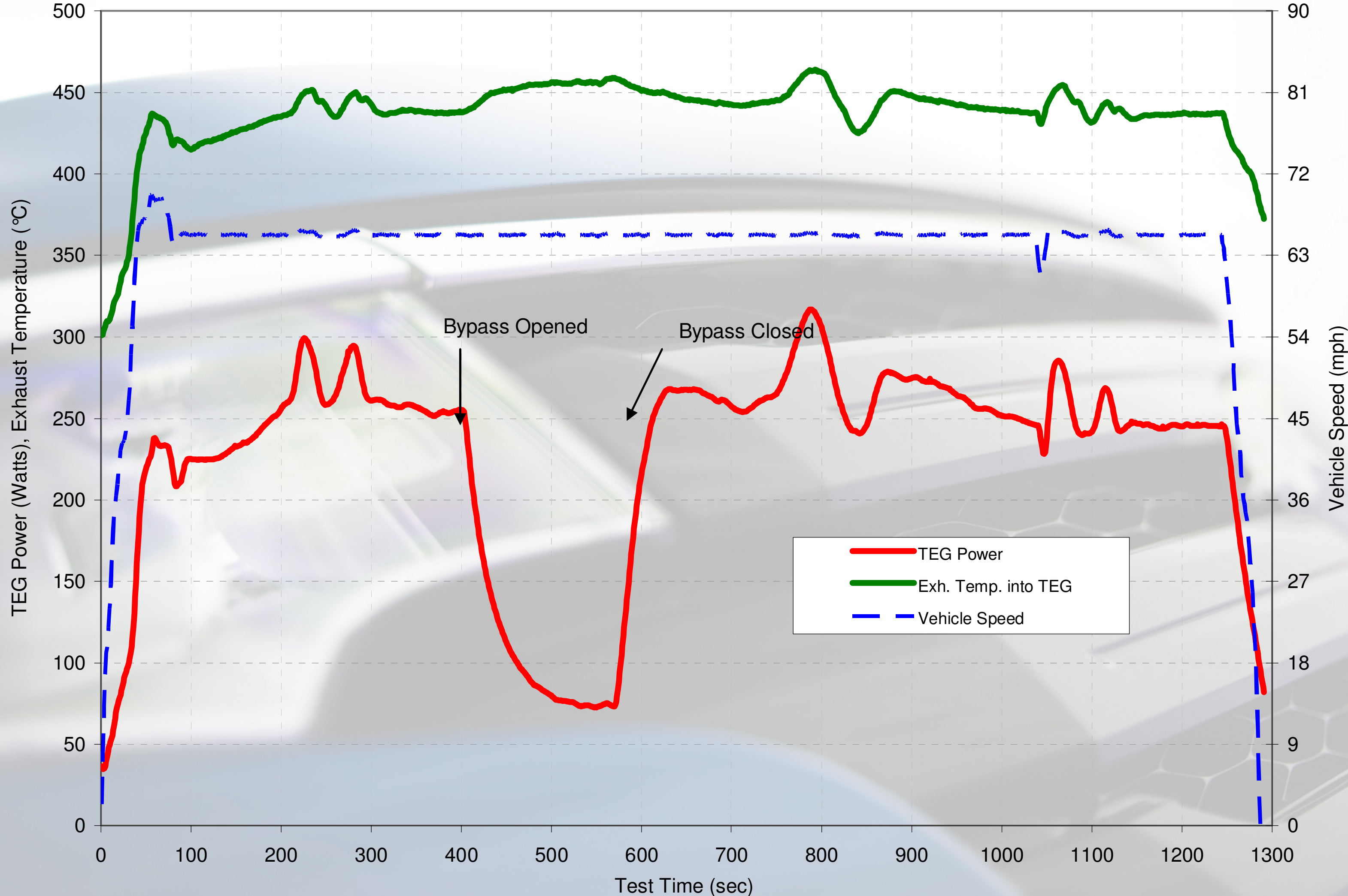
Driveshaft

Bypass Valve

Electrical Connections

TEG

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℃ to -30℃ ambient conditions
  - Full accessory loads, including current spikes
  - Reduce TOTAL fuel consumption, weight, and cost compared to an alternator/battery system

- **Ability to <u>replace</u> 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**

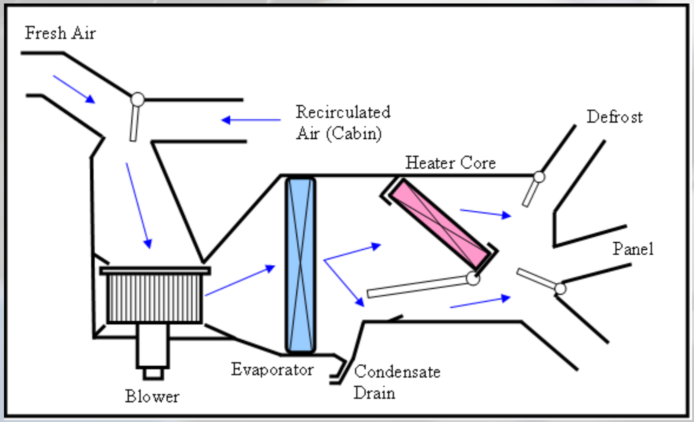
Automotive HVAC Systems

Objective: Provide occupant comfort over a broad range of ambient conditions

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

<u>Considerations for a TED</u>:

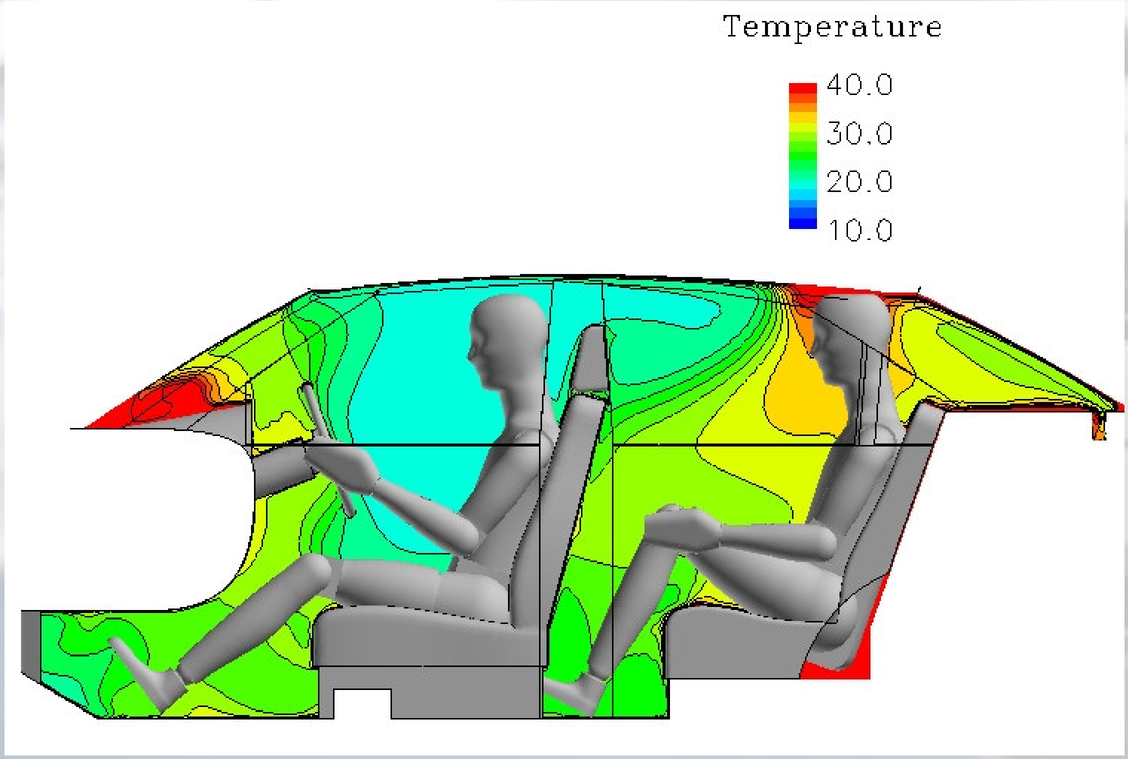
- Location, air flow rate, and temperature of localized air streams
  - Directly affect occupant comfort
  - Optimized for both heating and cooling modes
- Control strategy is critical to HVAC system performance and energy consumption
  - Best effective use of TED for zonal design may be to complement 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

HVAC Mode	Average Interior Temperature	Breath Temperature	Floor Temperature
A/C	20 – 30°C	20 – 25°C	22 – 35°C
Heating	22 - 30°C	15 – 25°C	27 – 37°C



HVAC System Design - Occupant Thermal Comfort Optimization

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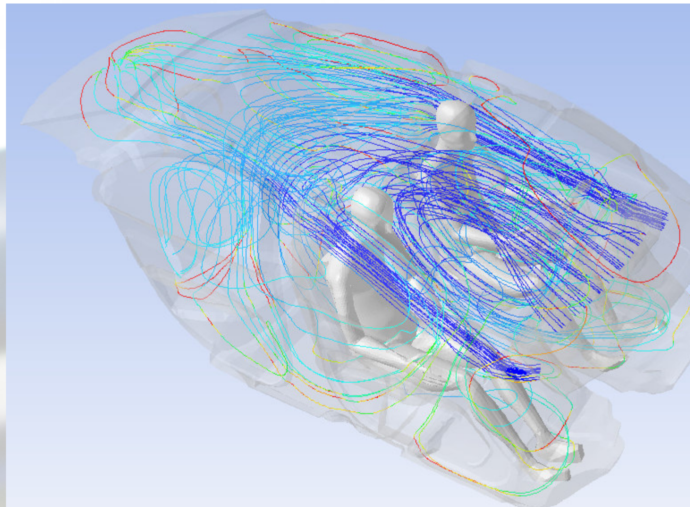
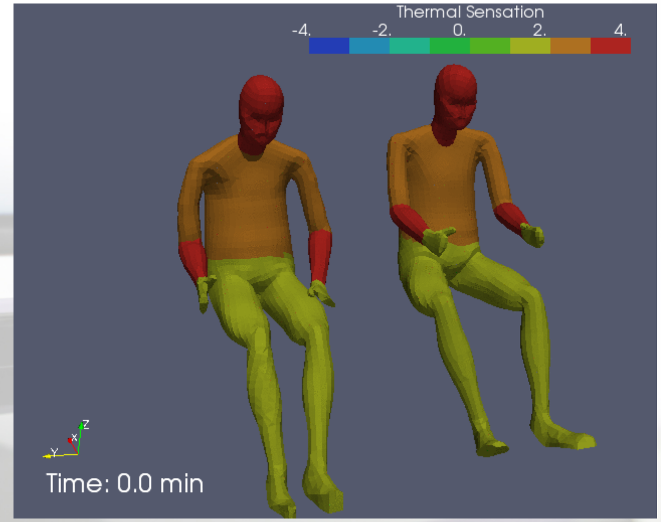
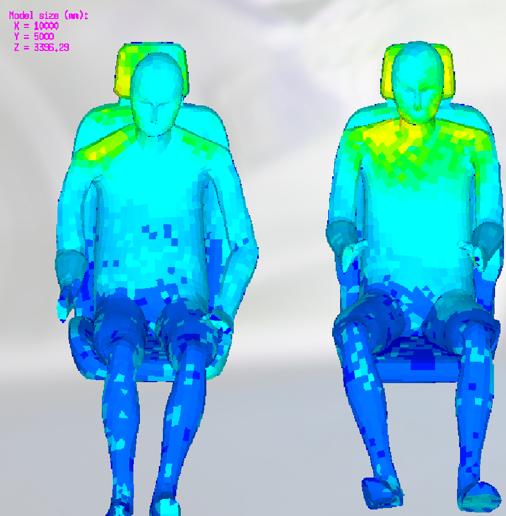
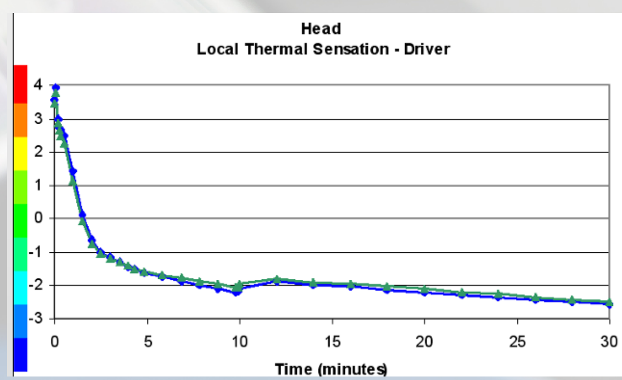
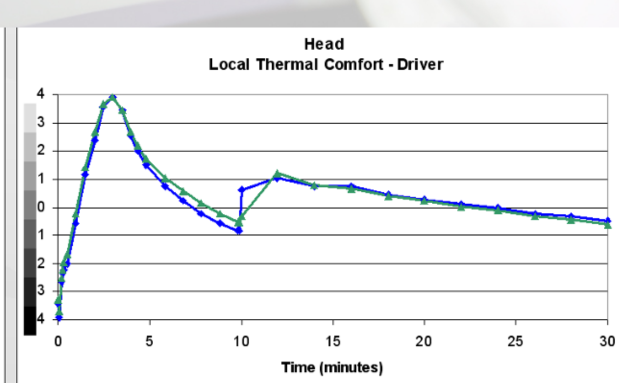






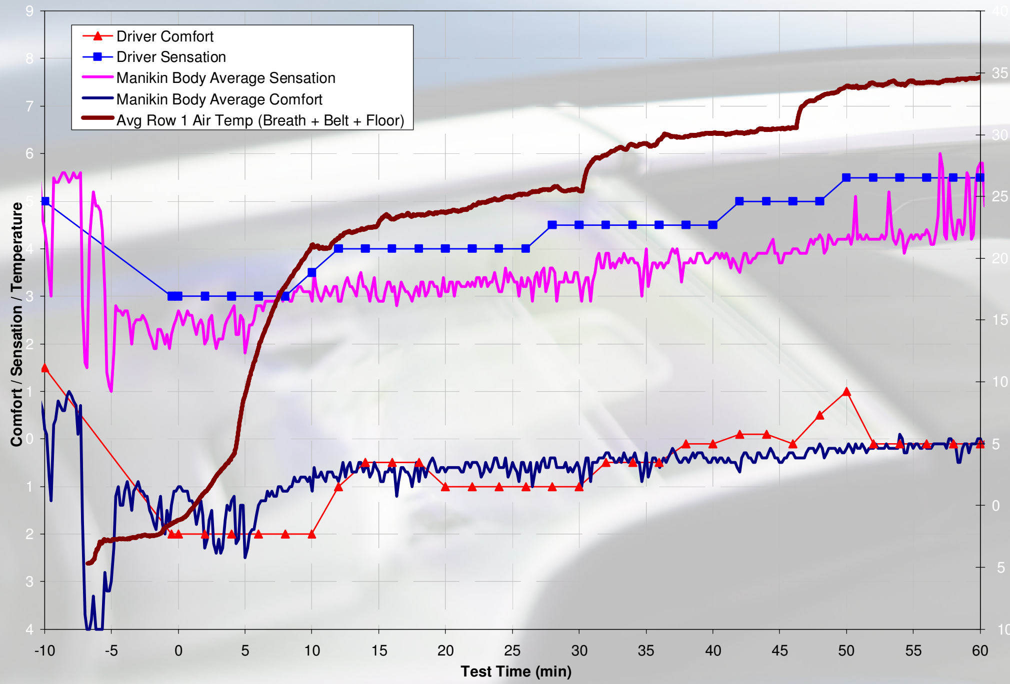




Model-based design allows for flexibility in analyzing key parameters

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