Overview

Timeline

- **Project start date:** FY12
- **Project end date:** FY15
- **Percent complete:** 85%

Budget

- **Total project funding (to date):** $3,350K
- **Funding received in FY14:** $900K
- **Funding for FY15:** $750K
- **Partner in-kind cost share:** $225K*

* Not included in total

Barriers

- **Range** – impact of climate control on range
- **Cost** – cost premium for electric drive vehicles (EDVs)
- **Life** – battery life impacted by temperature

Partners

- **Interactions/Collaborations:**
  - Ford
  - Measurement Technology Northwest (MTNW)
  - ThermoAnalytics, Inc.
  - Gentherm
  - Eastman Chemical (Solutia)
  - Argonne National Laboratory (ANL)
- **Project Lead:**
  - National Renewable Energy Laboratory (NREL)
Relevance – Overcoming Barriers to EDVs

• **Range**
  o Reducing climate control energy requirements in warm and cold weather will improve real-world driving range and increase adoption of EDVs.

• **Cost**
  o Less stored energy required for climate control will enable smaller batteries for the same driving range, reducing electric vehicle cost and weight.

• **Life**
  o Improved cabin thermal management can help reduce battery degradation caused by high temperatures.

• **Thermal Comfort**
  o A focus on human thermal comfort is required for advanced climate control design.
Relevance – Climate Control Impact on EDV Range

Climate Control Impact on Focus EV Driving Range - UDDS Cycle

Range [mi.]

- Max. Heating 20°F Ambient: 59.3%
- No Heating 20°F Ambient
- No Cooling 95°F Ambient: 53.7%
- Max. Cooling 95°F Ambient

Source: Argonne National Laboratory’s Advanced Powertrain Research Facility
Relevance – Support Broad VTO Efforts

- **U.S. DRIVE Vehicle Systems Analysis Technical Team (VSATT)**
- **U.S. Department of Energy (DOE) Vehicle Technologies Office (VTO) Multi-Year Project Plan (MYPP)**
  - “...development of advanced vehicles and components to maximize vehicle efficiency...”
- **President’s EV Everywhere Grand Challenge**
  - “EV Everywhere will focus on the following specific research areas:
    - Energy Load Reduction and Energy Management
    - Advanced HVAC Equipment
    - Cabin Pre-Conditioning”
Relevance – Objectives

• Minimize the impact of climate control on grid-connected EDV range.
  o Reduce vehicle thermal loads for heating and cooling.
  o Focus heating/cooling on occupants.
  o Develop a process to calculate range impact of HVAC energy savings.

• Improve techniques for occupant thermal comfort evaluation.

• Increase electric range by 10% during operation of the climate control system through improved thermal management.
  o Maintain or improve occupant thermal comfort.
## Approach – Milestones

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>Description</th>
<th>Status</th>
</tr>
</thead>
</table>
| Q1 Dec. 2014 | **Milestone**  
• Develop test plan and prepare vehicle configurations for cold weather outdoor thermal testing. | Complete |
| Q2 Mar. 2015 | **Milestone**  
• Complete cold weather testing on the Focus Electric vehicles to assess zonal heating strategies. | Complete |
| Q3 June 2015 | **Milestone**  
• Submit a presentation on the project and present at DOE’s Annual Merit Review. | On Track |
| Q4 Sept. 2015 | **Milestone**  
• Calculate the expected impact on EDV range and compare to 10% improvement goal.  
• Submit a progress summary of the task for the DOE annual report. | On Track |
Approach

• **Coordinate closely with the auto industry to obtain relevant results that will impact the efficiency of future vehicles.**
  - Ford (CRADA partner), automotive suppliers, and developers of hardware/software tools for thermal comfort assessment.

• **Develop and evaluate strategies to reduce climate control loads in EVs.**
  - Conduct outdoor thermal tests to quantify thermal soak and transient heating/cooling impacts.
  - Perform thermal analyses to explore load reduction concepts and evaluate occupant thermal comfort.

• **Leverage results and resources from other DOE projects.**
  - Zonal climate control approach developed under thermoelectric HVAC projects.
  - Vehicle test data and models from other national laboratories.

• **Utilize and enhance thermal comfort evaluation tools to enable advanced HVAC design from an occupant thermal comfort perspective.**

CRADA = cooperative research and development agreement
HVAC = heating, ventilation and air conditioning
Approach – Focus Areas

Reduce Thermal Loads

- Reflective glazing/film
- Window shades
- Cabin shading

Maintain or Improve Thermal Comfort

- Increased headliner insulation

Heated interior surfaces:

- Steering wheel
- Driver seat
- Floor mat

Solar load reduction:

- Reflective glazing/film
- Window shades
- Cabin shading

Active cabin pre-ventilation

Advanced seating concepts

Zonal air vents for heating and cooling
Approach: Vehicle Testing
Warm and Cold Weather Outdoor Thermal Testing of EDVs at NREL
Accomplishments: Vehicle Testing – Cooling
Thermal Load Reduction Strategies to Decrease Solar Energy Stored in Cabin

- **Shading Canopy**
  - Entire vehicle shaded

- **White Film**
  - Applied to all glazing

- **Solar-Reflective Film**
  - Applied to all glazing

- **Cabin Pre-Ventilation**
  - Initiated before cool-down

- **IR-Reflective Windshield**
  - Windshield only
Accomplishments: Vehicle Testing – Cooling

Thermal Load Reduction Strategies Reduced Soak Temp. and A/C Energy Use

- HVAC Energy Savings @ 20 min.
- Cabin Air Temperature Reduction

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Energy Savings after 20-min. Cool-down [kWh]</th>
<th>Cabin Air Temperature Reduction [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shading Canopy</td>
<td>1.20</td>
<td>18.1</td>
</tr>
<tr>
<td>White Film (all glazing)</td>
<td>0.85</td>
<td>9.2</td>
</tr>
<tr>
<td>SR Film (all glazing)</td>
<td>0.74</td>
<td>5.3</td>
</tr>
<tr>
<td>IRR WS Only</td>
<td>0.21</td>
<td>4.0</td>
</tr>
<tr>
<td>IRR WS + Pre-vent. (15-min.)</td>
<td>0.56</td>
<td>9.9</td>
</tr>
<tr>
<td>Pre-vent.</td>
<td>0.48</td>
<td>5.8</td>
</tr>
</tbody>
</table>

SR: solar-reflective
IRR: infrared-reflective
WS: windshield
Accomplishments: Vehicle Testing – Cooling
Thermal Load Reduction Strategies Combined with Zonal Air Flow

Cabin Pre-Ventilation
15 minutes before cool-down

Solar Load Reduction
Solar-Reflective Glazing Film
IR-Reflective Windshield

Zonal Air Flow
• Overhead vent
• Panel vent
• Foot vent

Solar Load Reduction

Inter-Temperature
Blower Power
Accomplishments: Vehicle Testing – Cooling
Zonal Configurations Had Lower Driver Air Temperatures and Lower Flow Rates

Driver Air Temp. @ 20 min.

Baseline Temp = 29.4 °C
Accomplishments: Vehicle Testing – Cooling
Zonal Configurations Resulted in A/C Energy Savings

Baseline Temp = 29.4 °C

Maximum Potential Savings Case
1. Maximum A/C settings
2. Hot soak with solar load
3. Transient cool-down.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Driver Air Temp. @ 20 min</th>
<th>HVAC Energy Savings @ 20 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel Vents Blower 7</td>
<td>29.2</td>
<td></td>
</tr>
<tr>
<td>Panel + Overhead Vent Blower 7</td>
<td>24.6</td>
<td>0.12</td>
</tr>
<tr>
<td>Panel + Lap Vent Blower 7</td>
<td>25.5</td>
<td>0.12</td>
</tr>
<tr>
<td>Driver Panel Vents Blower 5</td>
<td>31.7</td>
<td>0.79</td>
</tr>
<tr>
<td>Panel + Overhead Vent Blower 5</td>
<td>28.0</td>
<td>0.65</td>
</tr>
<tr>
<td>Panel + Footwell Vent Blower 5</td>
<td>28.8</td>
<td>0.58</td>
</tr>
<tr>
<td>Combined Cooling Config. Blower 4</td>
<td>27.6</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Driver Air Temp. [°C]
Cumulative HVAC Energy Savings [kWh]
Accomplishments: Vehicle Testing – Heating

Zonal Heating Test Configurations Utilized Zonal Air Flow and Heated Surfaces

Zonal #1
• Driver vent only

Zonal #2
• Driver vent + lap vent

Zonal #3
• Zonal driver vents + heated seat

Zonal #4
• Zonal driver vents + heated seat, steering wheel and floor mat
Accomplishments: Vehicle Testing – Heating
Zonal Heating Reduced HVAC Energy, Maintained Driver Thermal Sensation

<table>
<thead>
<tr>
<th></th>
<th>Time to Neutral Thermal Sensation [min.]</th>
<th>Cumulative Energy Savings @ 20 minutes [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>N/A</td>
<td>0%</td>
</tr>
<tr>
<td>Zonal #1</td>
<td>8</td>
<td>5.5%</td>
</tr>
<tr>
<td>Zonal #2</td>
<td>10</td>
<td>9.4%</td>
</tr>
<tr>
<td>Zonal #3</td>
<td>12</td>
<td>13.6%</td>
</tr>
<tr>
<td>Zonal #4</td>
<td>10</td>
<td>28.5%</td>
</tr>
</tbody>
</table>
Accomplishments: Vehicle Simulation – Range Impact
A/C Power from Testing Input into Focus Electric Autonomie Model

Measured compressor power

Autonomie Focus EV model
Accomplishments: Vehicle Simulation – Range Impact

Potential for Zonal Climate Control to Improve EV Range

-36.9%  67.0  +15.3%  76.9  +32.2%
No A/C  Baseline A/C  Overhead A/C  Combined Config.

Range [mi.]
Accomplishments: Vehicle Simulation – Range Impact
Potential for Zonal Climate Control to Improve EV Range

Range improvement for moderate environmental conditions and longer trip lengths will be less.
Collaboration and Coordination

• **Automotive Industry**
  - Ford – CRADA partner
  - Gentherm
  - Eastman Chemical (Solutia)

• **Thermal Manikin**
  - Measurement Technology Northwest

• **Software**
  - ThermoAnalytics, Inc.

• **DOE VTO Crosscutting**
  - John Fairbanks – leveraging thermoelectric research

• **National Lab Crosscutting**
  - ANL – vehicle model and test data
Future Work

• Remaining FY15
  o Determine driving range impact of zonal heating from cold weather test results.
  o Continue thermal analyses for heating conditions.
  o Calculate expected impact on range for a typical EV in the United States.
  o Compare test and analysis results against project target of 10% range improvement.

• Project is scheduled to conclude after FY15.
Summary

**DOE Mission Support**

- Reduce EDV climate control energy use
- Improve EDV range and reduce costs
- Accelerate consumer acceptance and EDV usage
- Reduce petroleum consumption

**Collaborations**

- Automobile manufacturer
- Automotive Tier 1 suppliers
- Software developers
- National laboratories.
Summary – Technical Accomplishments

• Advanced glazing and pre-ventilation can significantly reduce soak temperatures, saving energy during cool-down.

• A thermal manikin was utilized to demonstrate zonal cooling techniques to decrease A/C loads without sacrificing occupant comfort.
  o 0.58 kWh (45.5%) saved with driver-only vent configuration (using existing air ducts and vents)
  o 0.92 kWh (66.5%) saved with combined TLR and zonal strategies.

• Autonomie modeling shows potential improvement in EV range over Baseline A/C:
  o 11% to 32% with combined strategies (TLR + overhead A/C).

• Zonal heating has the potential to decrease warm-up time and save energy during transient heating.
  o Up to 0.34 kWh (28.5%) less heating energy using driver-focused air flow and heated surfaces.
Acknowledgements and Contacts

Special thanks to:
David Anderson    Lee Slezak
Vehicle Technologies Office

For more information:
John P. Rugh – Task leader and PI
National Renewable Energy Laboratory
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Team Members:
Larry Chaney    Cory Kreutzer
Matt Jeffers    Jeff Tomerlin
## Responses to Previous Year Reviewers’ Comments

<table>
<thead>
<tr>
<th>Reviewer Comments</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reviewer said it was not clear in each case if the temperature reduction was a</td>
<td>This was addressed in round two of summer testing this past year; cool-down tests were completed to quantify the A/C energy savings resulting from thermal soak temperature reductions.</td>
</tr>
<tr>
<td>significant improvement in performance.</td>
<td></td>
</tr>
<tr>
<td>Reviewer noted that rating climate control system performance can be subjective</td>
<td>Engineering evaluation was used for heating tests because the thermal manikin used at the time was unable to measure the impact of heating through contact surfaces; our collaboration with industry partners has contributed to improved thermal comfort tools to overcome this limitation.</td>
</tr>
<tr>
<td>and asked about diversity in the test group of participants.</td>
<td></td>
</tr>
<tr>
<td>Reviewer found the project target of 10% range increase to be insufficient in</td>
<td>Setting an improvement target that completely eliminates the range penalty suggests that no energy would be used for heating/cooling, which is unrealistic; a 10% increase is a significant, yet achievable, improvement, but the overall goal is always to minimize climate control loads, strving for greater than 10%.</td>
</tr>
<tr>
<td>magnitude to overcome range penalty of 20%–40% due to climate control loads;</td>
<td></td>
</tr>
<tr>
<td>technical barrier needs to be matched with equally ambitious goals.</td>
<td></td>
</tr>
</tbody>
</table>
Photo Credits

Slide 1  Matt Jeffers, NREL
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