NREL
NATIONAL RENEWABLE ENERGY LABORATORY

2016 VTO Annual Merit Review
and Peer Evaluation Meeting

Design and Implementation of a Thermal Load Reduction System in a Hyundai PHEV

P.I.: Cory Kreutzer
John Rugh, Task Leader

National Renewable Energy Laboratory

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Project ID: VS165

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

Timeline

- **Project start date: FY15**
- **Project end date: FY17**
- **Percent complete: 40%**

Barriers

- **Risk Aversion:** *Manufacturers are reluctant to invest in and introduce new technologies*
- **Cost:** *Effective, timely evaluation of advanced vehicular components and configurations is needed.*
- **Range Anxiety:** *Large climate control loads can contribute significantly to electric drive vehicle (EDV) range anxiety*

Budget

Fully Funded FOA Project

- **Total project funding: $3,054,817**
  - DOE share: $ 2,443,790
  - Contractor share*: $ 611,027
- **Funding received in FY14: $ 2,443,790**
- **Funding for FY16: $ 0**

** Contractor share represents 20% cost share for the project*

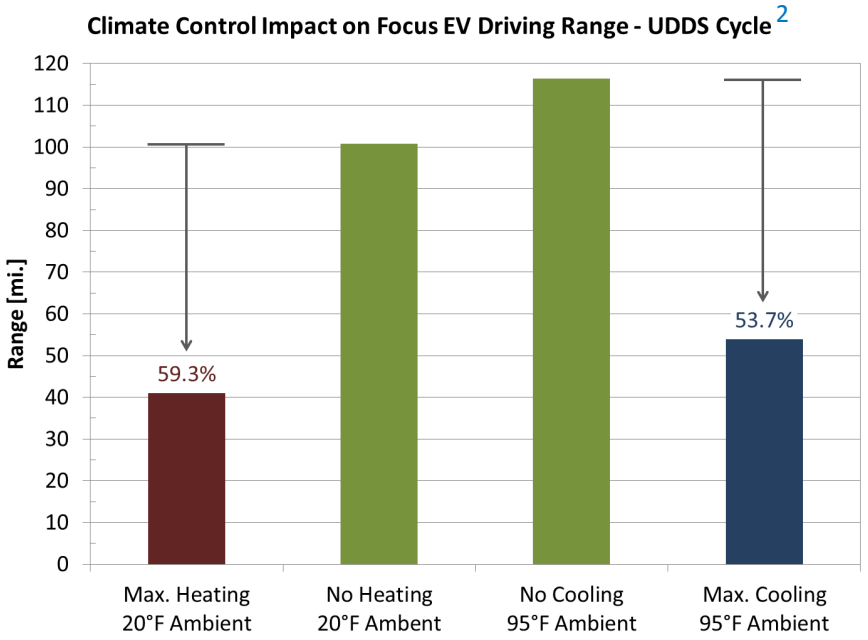
Partners

- **Interactions/collaborations:**
  - Hyundai America Technical Center, Inc. (HATCI)
  - Hanon Systems
  - Sekisui Chemical Company, Ltd.
  - Pittsburgh Glass Works, LLC.
  - PPG Industries, Inc.
  - Gentherm, Inc.
  - 3M Company
- **Project lead:**
  - National Renewable Energy Laboratory

Relevance

THE CHALLENGE

- **Annual light-duty vehicle fuel use estimated at equivalent of 3 billion barrels of oil[1]**
- **Increased adoption of EDVs requires overcoming**
  - Original equipment manufacturer (OEM) averse to risk of adopting technologies
  - Limited vehicle range and associated customer range anxiety
  - Elevated cost of EDVs in comparison to existing conventional vehicles
- **Climate control loads significantly degrade EDV range**



1. *Data Source: EIA Annual Outlook 2015. http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf*, pg. A-17, accessed March 2016
2. *Data Source:* Argonne National Laboratory's Advanced Powertrain Research Facility

Relevance

THE OPPORTUNITY

- Reducing climate control loads enables
  - Smaller, cheaper batteries
  - Smaller climate control components
  - Advanced climate control strategies
- Load reduction system demonstration decreases OEM risk for adoption
- HVAC load reduction and advanced climate control design can positively impact occupant comfort

HVAC: heating, ventilating, and air conditioning

Alignment with DOE VTP

- Supports EERE 2016 – 2020 strategic plan
  - Develop technologies that enable the cost-effective production of EVs and reduce vehicle energy use[1]
- Supports meeting EV Everywhere Grand Challenge targets
  - Efficient climate control technologies

1. Office of Energy Efficiency and Renewable Energy 2016-2020 Strategic Plan and Implementing Framework. http://energy.gov/sites/prod/files/2015/12/f27/EERE_Strategic_Plan_12.16.15.pdf

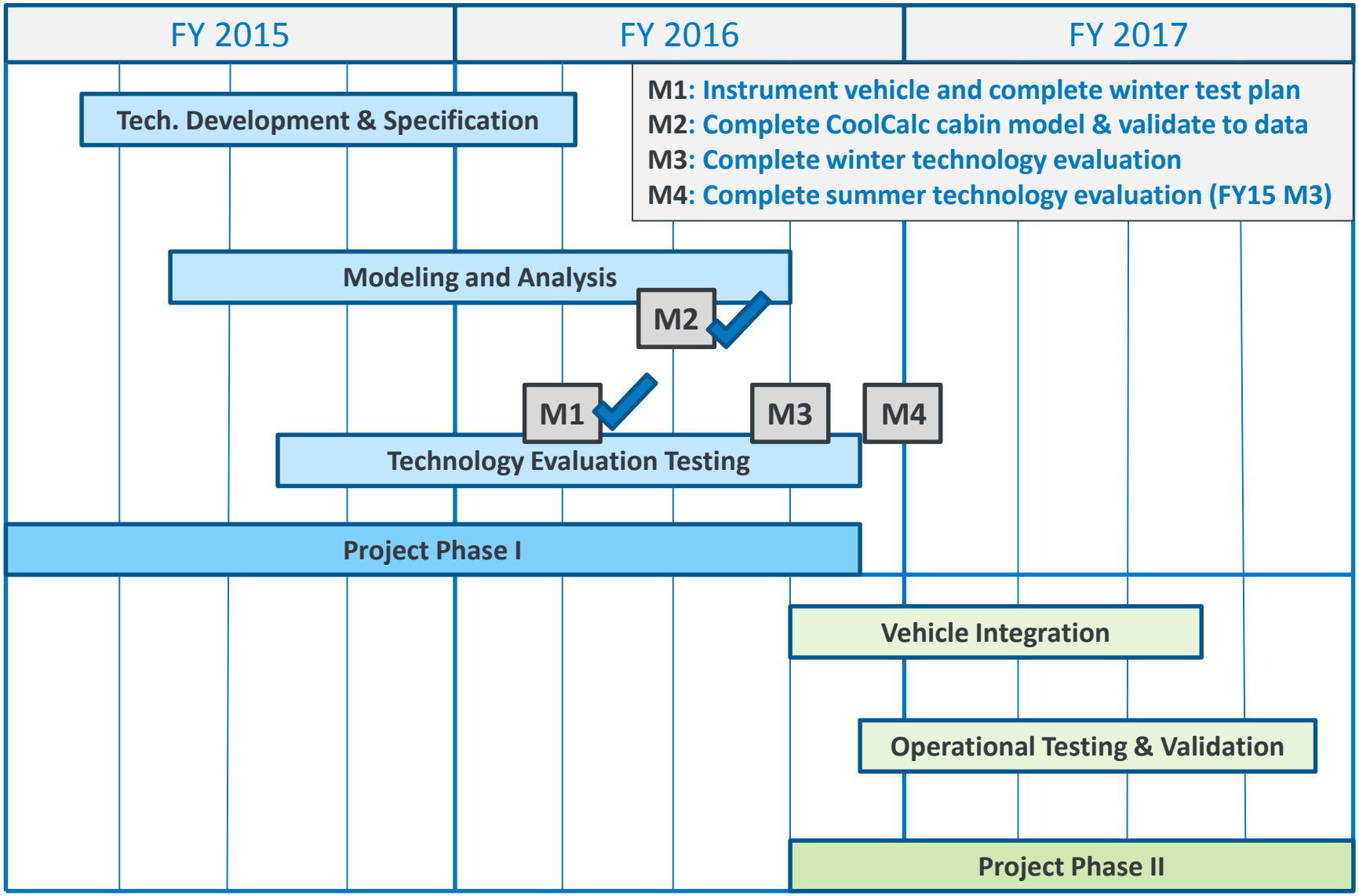
Relevance

THE GOAL

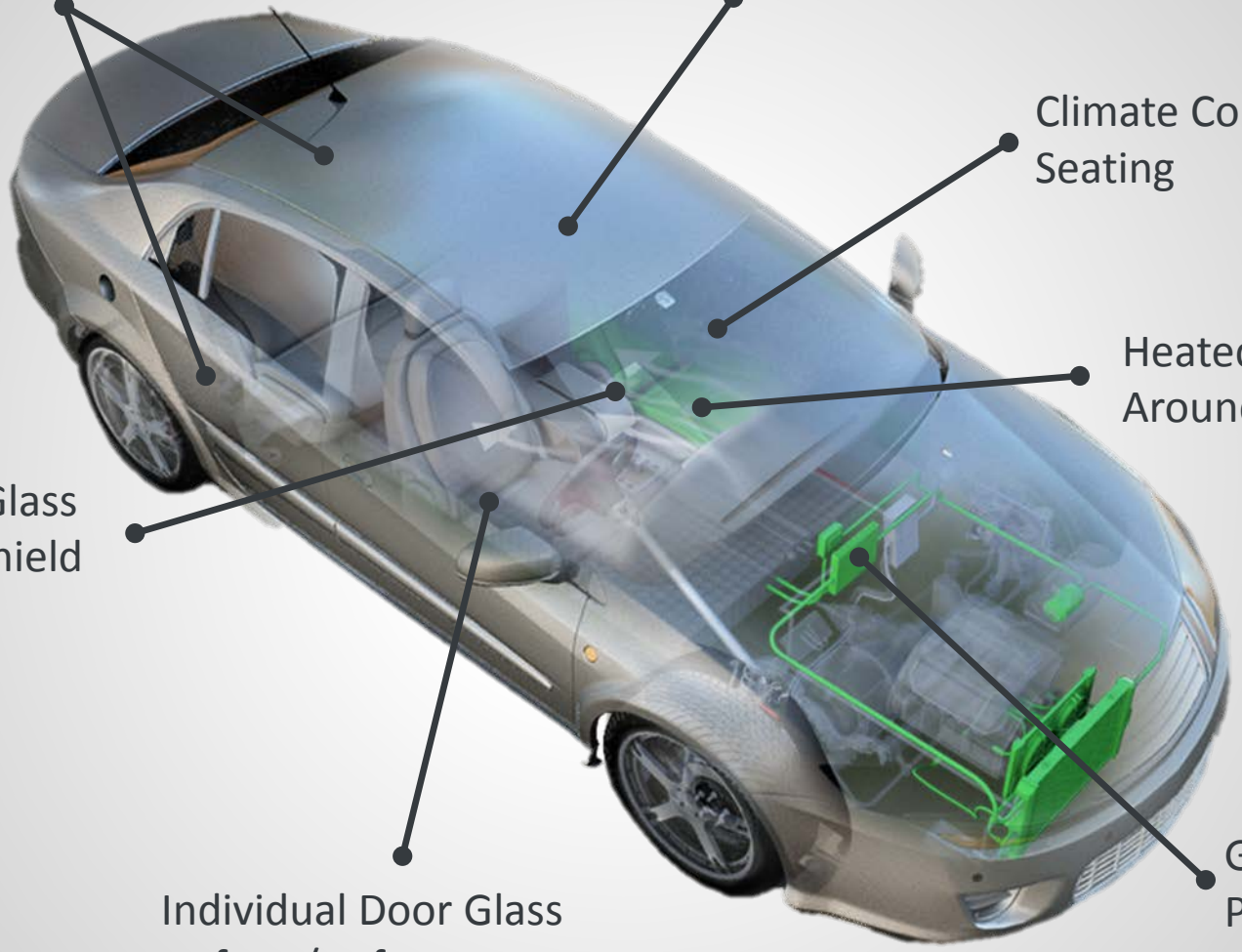
Increase grid-connected EDV range by 20% during operation of the climate control system over the standard vehicle configuration by reducing vehicle thermal loads

- Design and implement the thermal load reduction system on a production drivable vehicle
- Test the range impact over the combined city/highway drive cycle at peak heating and cooling conditions
- Maintain occupant thermal comfort in implemented system

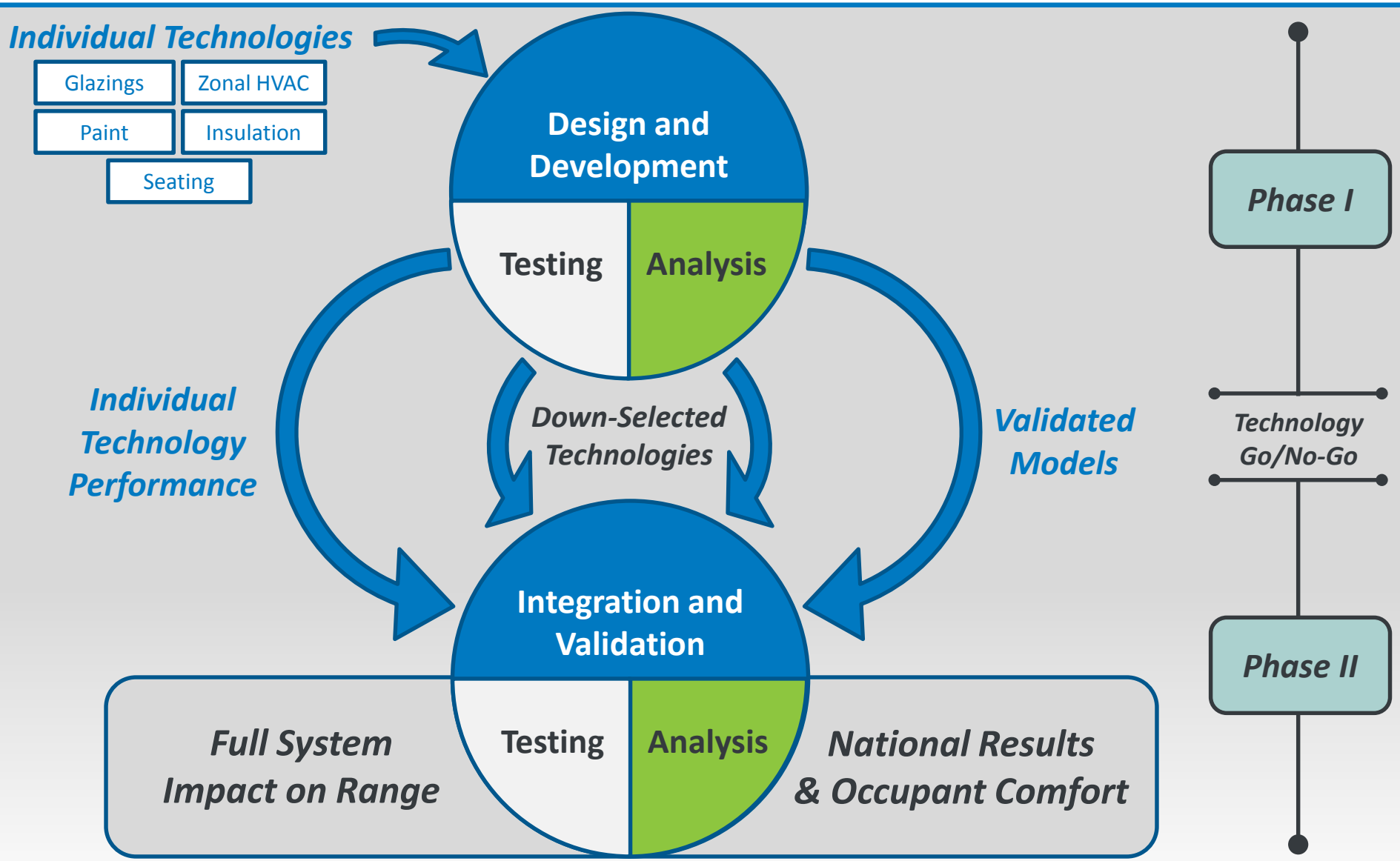
AOP Milestones 2016



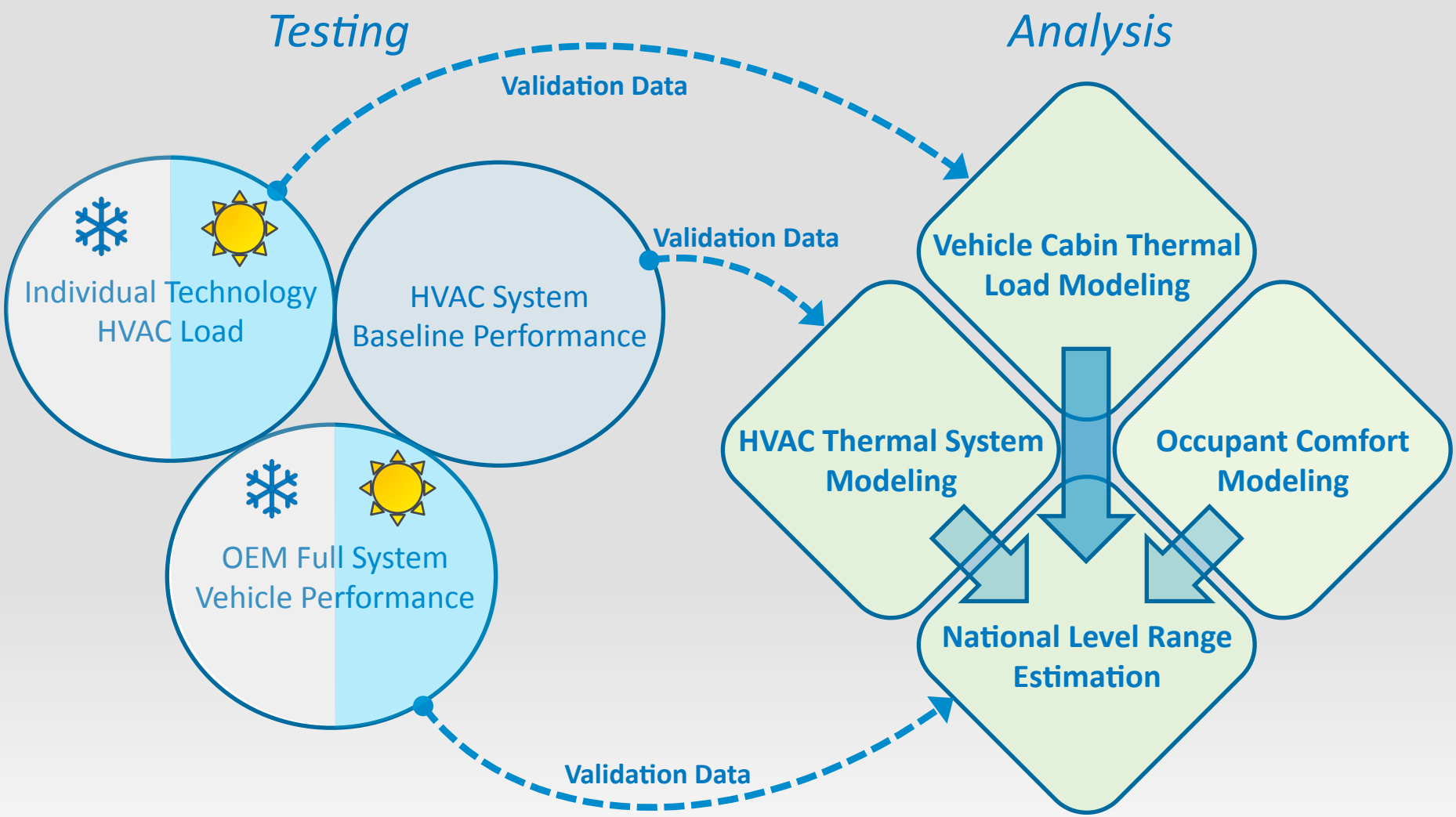
Approach – Technology Areas



Approach – Two-Phase Process



Approach – Testing and Analysis Strategy



Approach – Range Estimation Process

Light-Duty Range Estimation Process

Thermal

Vehicle Cabin Climate Control

Mechanical

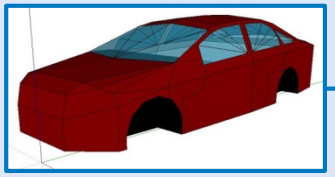
HVAC System Performance

Electrical

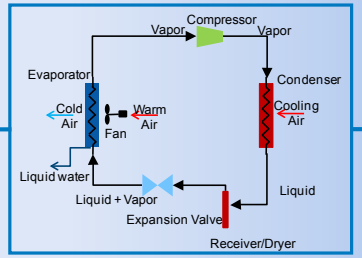
Power Conversion Performance

Electrical

Vehicle Performance Range



CoolCalc



CoolSim

FASTSim

Tools Used For Process

Accomplishments: Phase I Winter Baseline Testing

Strong correlation between vehicles at varying environmental conditions

Transient Warm-Up

HVAC Settings

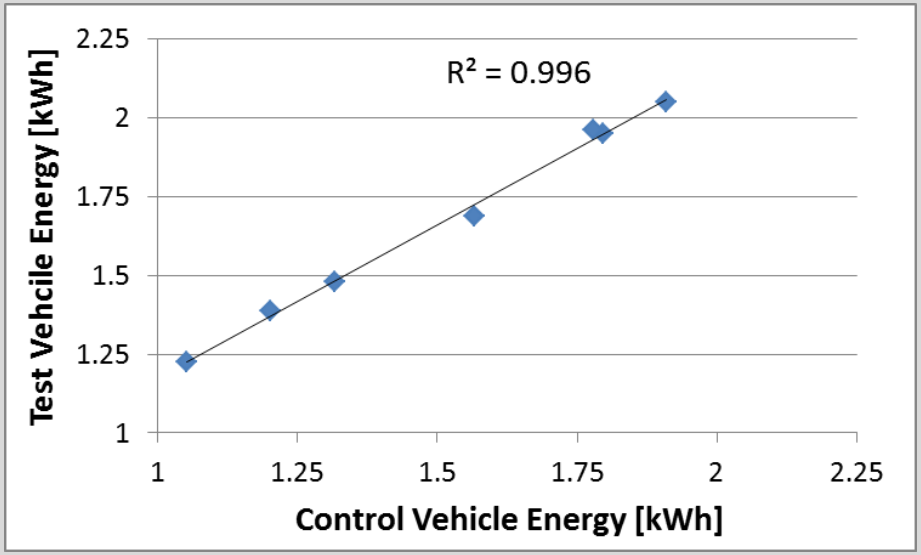
Mode	Panel & Floor
Temperature	Maximum
Blower	Maximum
Recirculation	Full / On

Steady-State Heating

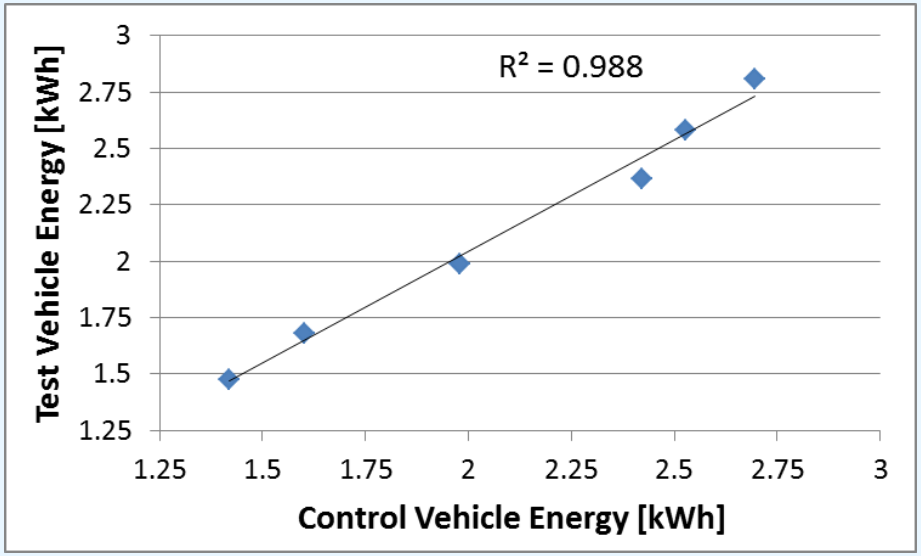
HVAC Settings

Mode	Auto
Temperature	72
Blower	Auto
Recirculation	Auto

Combined Heater Core and Positive Temperature Coefficient (PTC) Heater Energy Into Cabin



Combined Heater Core and PTC Heater Energy Into Cabin



Accomplishments: Phase I Winter Technology Evaluations

Insulation: 10.6% penalty in warm-up and 9.6% improvement in steady-state

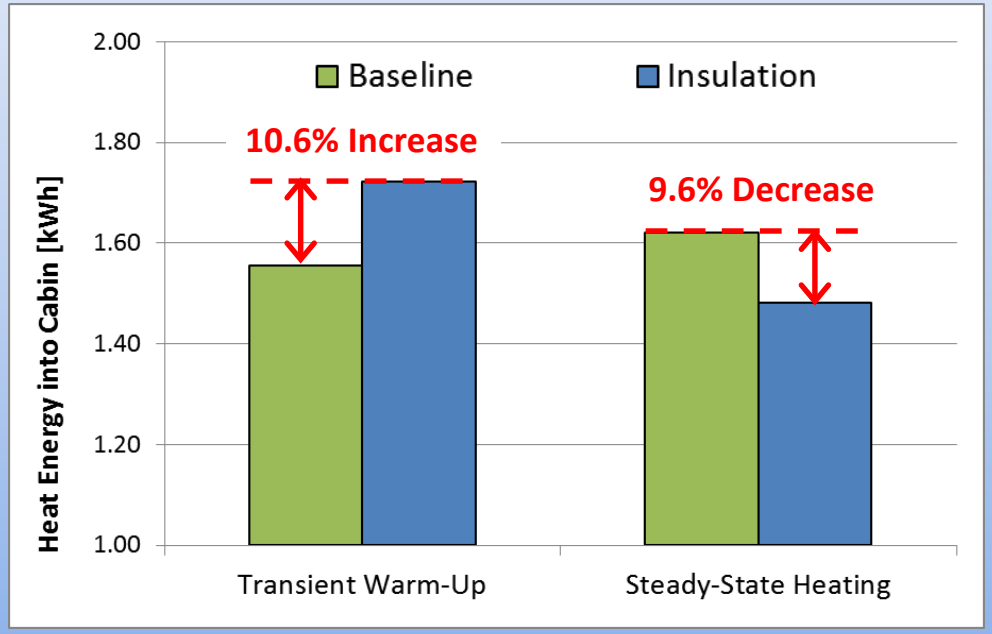
Baseline Door Panel

Areas with Increased Insulation
Headliner
Door Panels
Flooring
Package Tray
Pillars (where possible)

Increased Insulation Door Panel

- Results are six day average
- Experimental method could be over estimating the warm-up penalty of insulation (investigating)
- **Considerations for Phase II go/no-go include preconditioning, trip duration, soak time**

Combined Heater Core and PTC Heater Energy into Cabin



Accomplishments: Phase I Winter Technology Evaluations

Heated Surfaces: 2% penalty in warm-up and 29-59% improvement in steady-state heating

Test Vehicle: Heated Surfaces

Driver: Door arm rest and bolster, crash pad, console wall, console top, advanced heated seat

Passenger: Console wall, glove box, door arm rest and bolster

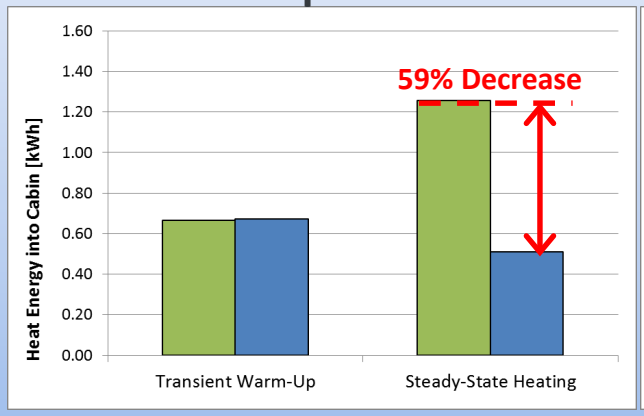
Test Method Highlights

Warm-Up: Energy until occupant sensation = 2

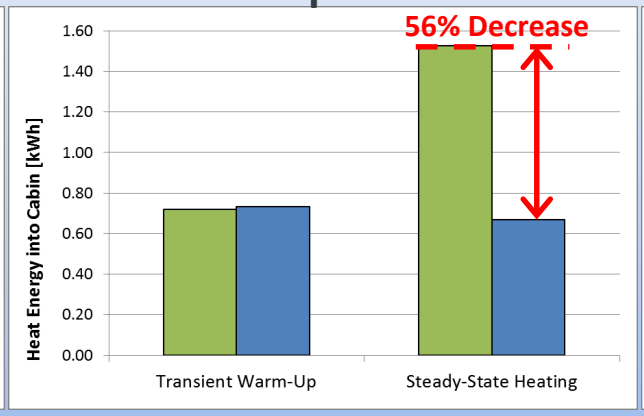
Steady-State: Auto temp. adjusted in modified vehicle until occupant at target sensation

Select Heated Surfaces

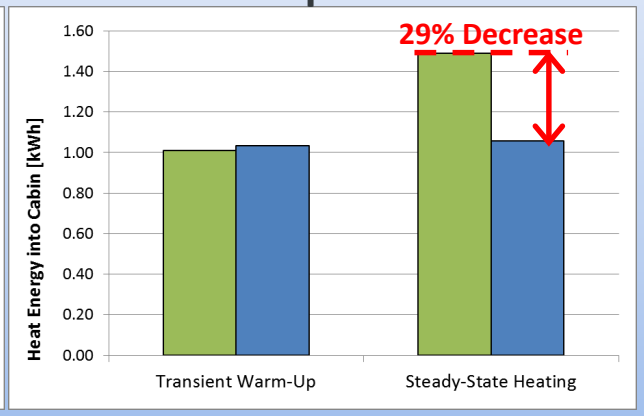
Occupant A



Occupant B



Occupant C



Test results for Colorado winter environment

Transient Warm-Up: 2% Penalty **Steady-State Heating: 29-59% Improvement**

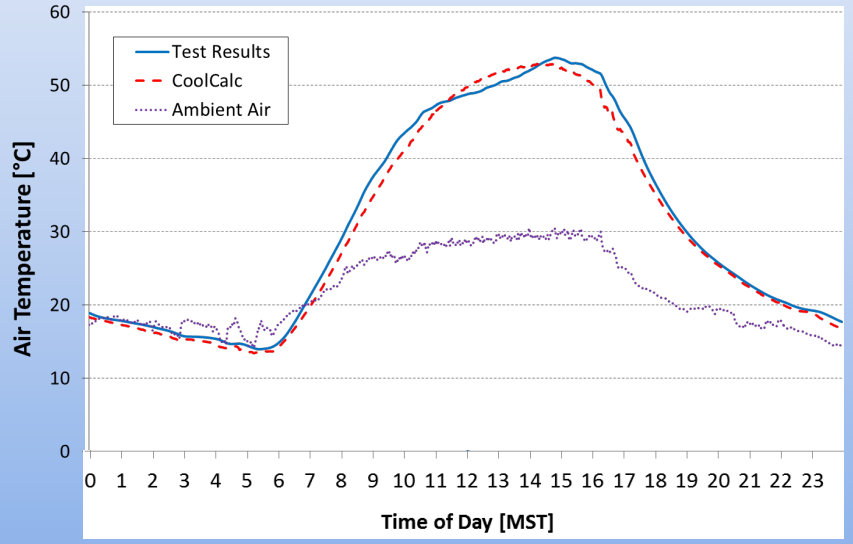
Accomplishments: CoolCalc Cabin Modeling

Sonata model developed and validated to experimental data to within 3.6%

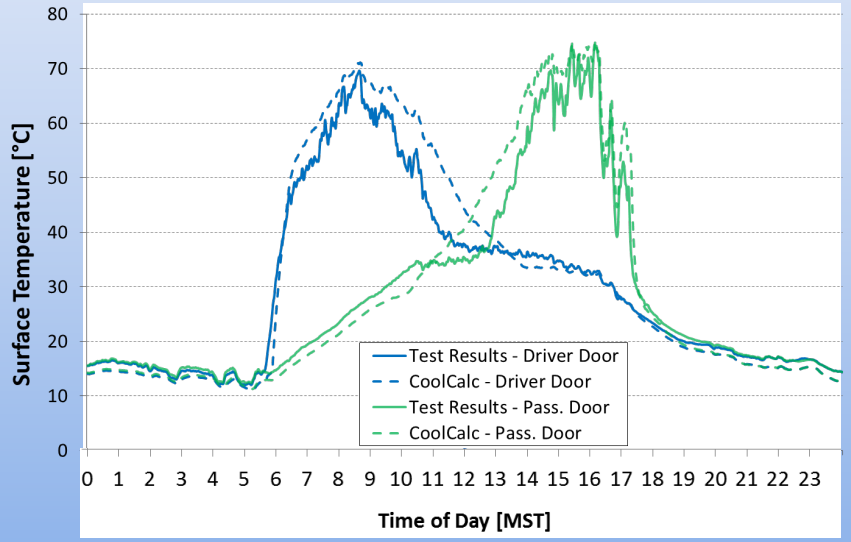
CoolCalc – Rapid HVAC load estimation tool

- A CoolCalc model of 2016 Hyundai Sonata was created
- Model was validated with summer outdoor experimental results
- Model and experimental results agree to within an average of 3.6% for cabin mean air temperature

Cabin Mean Air Temperature Comparison



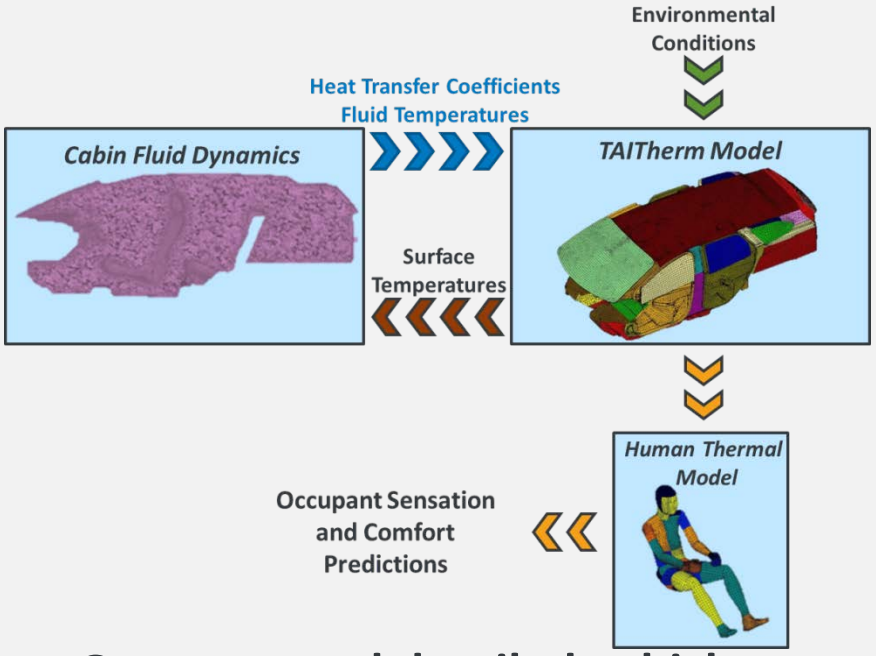
Door External Surface Temperature Comparison



Accomplishments – HVAC and detailed cabin modeling

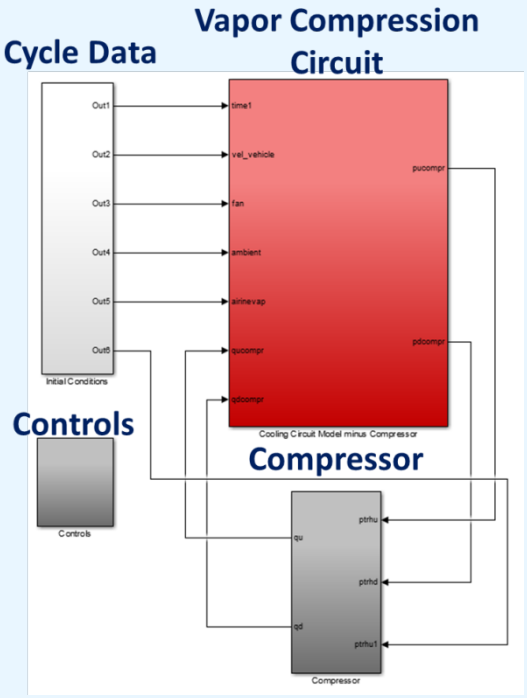
Vehicle specific HVAC model developed and detailed cabin model in-progress

Detailed Cabin and Comfort/Sensation Modeling



- Occupant and detailed vehicle thermal analysis tool development is in progress
- Interior volume computer-aided design is being refined/patched for mesh generation and TAITherm model

HVAC System Modeling

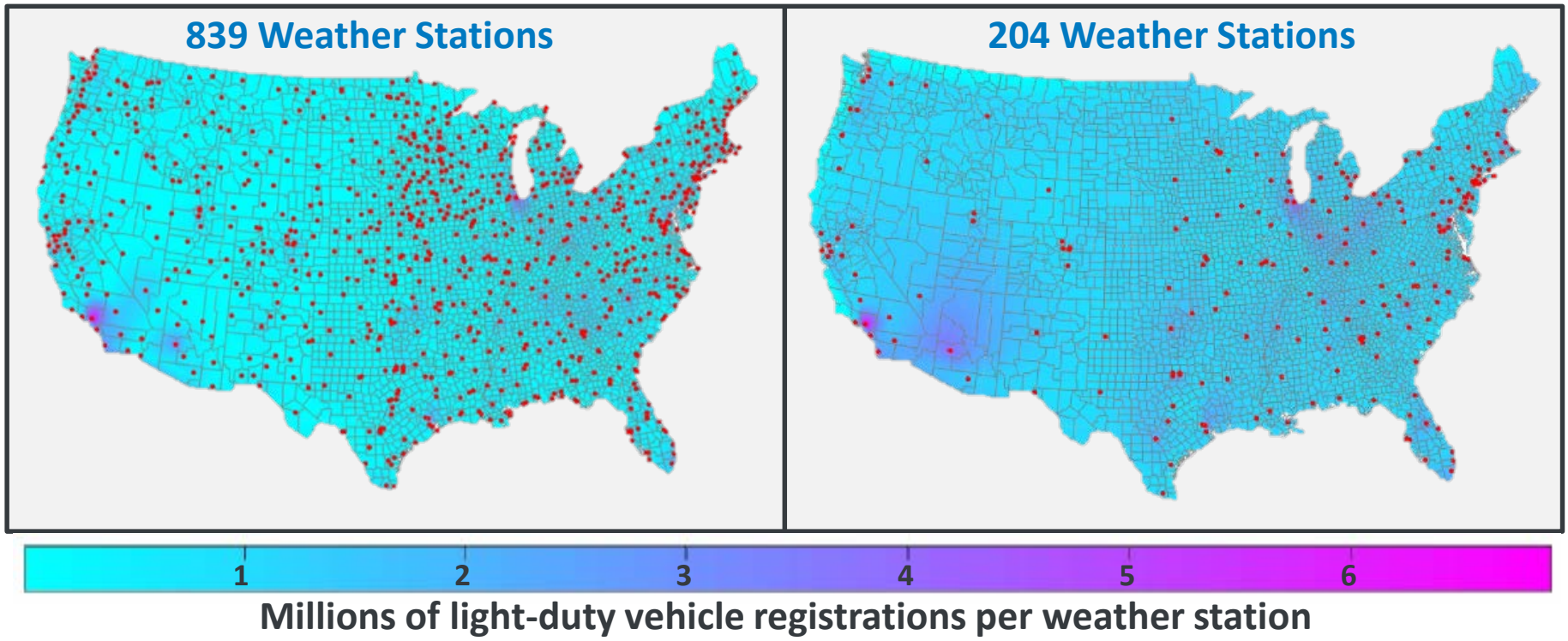


- A/C system model developed including control algorithm for preset evaporator capacity
- Model will be validated to experimental data collected by Hanon Systems

Accomplishments – National Level Analysis

Down-selection process completed for locations based on vehicle registrations

- **A process was developed to down-select typical meteorological year (TMY3) locations based on light-duty vehicle registrations[1]**
- **Purpose of the process**
  - Reduce the number of simulations for national-level analysis
  - Capture the most important weather environments across the country
  - Generate registration-based weighting factors for each location simulated



1. *Vehicle Registration Data Source: 2014 Polk Vehicle Registration Database,* https://www.ihs.com/btp/polk.html

Responses to FY15 AMR Reviewer Comments

FY15 AMR Question 1: Approach to performing the work – the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Comment:	…It is not clear whether advanced HVAC systems are being considered as part of this project….
Response:	The project is focused on technologies that reduce the thermal demand of the existing on-board HVAC system of the vehicle and does not directly include advanced HVAC systems as part of the scope. However, some of the technologies evaluated are intended to provide a more direct method of conditioning the occupant, which could be considered as part of an advanced HVAC system. Finally, these technologies could enable reduced HVAC system capacities and alternative systems that are not currently able to meet capacity/performance requirements.

FY15 AMR Question 4: Proposed future research-the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways.

Comment:	The reviewer stated that quantifiable results from actual test will be very valuable. Should consider hot weather testing in a desert environment rather than at NREL.
Response:	For Phase I of the project, both warm weather and cold weather testing of individual technologies will be completed at NREL. Testing during this phase of the project is aimed at maximizing repeatability and evaluating multiple technologies over the duration of a season. However, Phase II testing will be led by HATCI and will include more extreme environmental conditions similar to what was suggested.

Collaboration and Coordination

Hyundai America Technical Center

- Subtier Industry Partner
- Automotive OEM Supplier
- Lead on Phase II Technology Integration
- Lead on Phase II Full System Experimental Evaluation
- Technology Supplier (collaboration with Gentherm)

Hanon Systems

- Subtier Industry Partner
- Baseline HVAC System Experimental Evaluation
- HVAC System Modeling Support

Gentherm

- Subtier Industry Partner – in kind
- Door Defrost/Defog Technology Supplier
- Heated Surfaces Technology Supplier (collaboration)
- Advanced Seating Technology Supplier (collaboration)

Pittsburgh Glass Works

- Subtier Industry Partner
- Glass Package Manufacturer
- Advanced Glass Technology Supplier

PPG Industries

- Subtier Industry Partner
- Automotive Paint Supplier
- Advanced Paint Technology Supplier

Sekisui

- Subtier Industry Partner
- Advanced Solar Control Interlayer Supplier

3M

- Subtier Industry Partner – in kind
- Advanced Solar Control Film Supplier
- Advanced Insulation Technology Supplier

Proposed Future Work

Phase I: Technology Design and Development (FY16)

- Complete summer technology evaluations
- Validate HVAC system model to experimental data
- Complete development of CAE & comfort/sensation model development and run analyses
- Complete national-level analysis components, including time-of-day usage, drive duration, and drive cycle selection(s)
- Perform Phase I technology evaluation Go/No-Go for Phase II

Phase II: Technology Integration and Validation (FY16–17)

- Integrate thermal load reduction technologies into drivable vehicle system
- Perform operational cold weather, hot weather, and environmental chamber testing at Hyundai America Technical Center facilities
- Refine models with individual technology experimental results and perform national-level analysis
- Final vehicle demonstration and project summary presentation to DOE

Summary

- The project's focus is to implement a thermal load reduction system into a GCEDV production vehicle and quantify the impact on thermal comfort, fuel use, and EV range
- Key industry partners enable production-ready and cost-effective technologies and vehicle-level integration
- Testing and modeling/analysis are used synergistically to quantify system performance and national relevance

Accomplishments

- Completed Phase I winter baseline testing with a strong correlation between vehicles in varying environmental conditions
- Characterized the cold weather performance of added insulation, obtaining a 10.6% penalty in warm-up and 9.6% advantage in steady-state
- Characterized the cold weather performance of heated surfaces, obtaining a 2% penalty in warm-up and 48% improvement in steady-state heating
- A Hyundai Sonata CoolCalc model was developed and validated to experimental data
- A vehicle-specific HVAC model has been developed, and a detailed cabin/occupant model is in development
- A national-level range estimation process is in development, and the down-selection process for weather locations based on vehicle registrations is complete

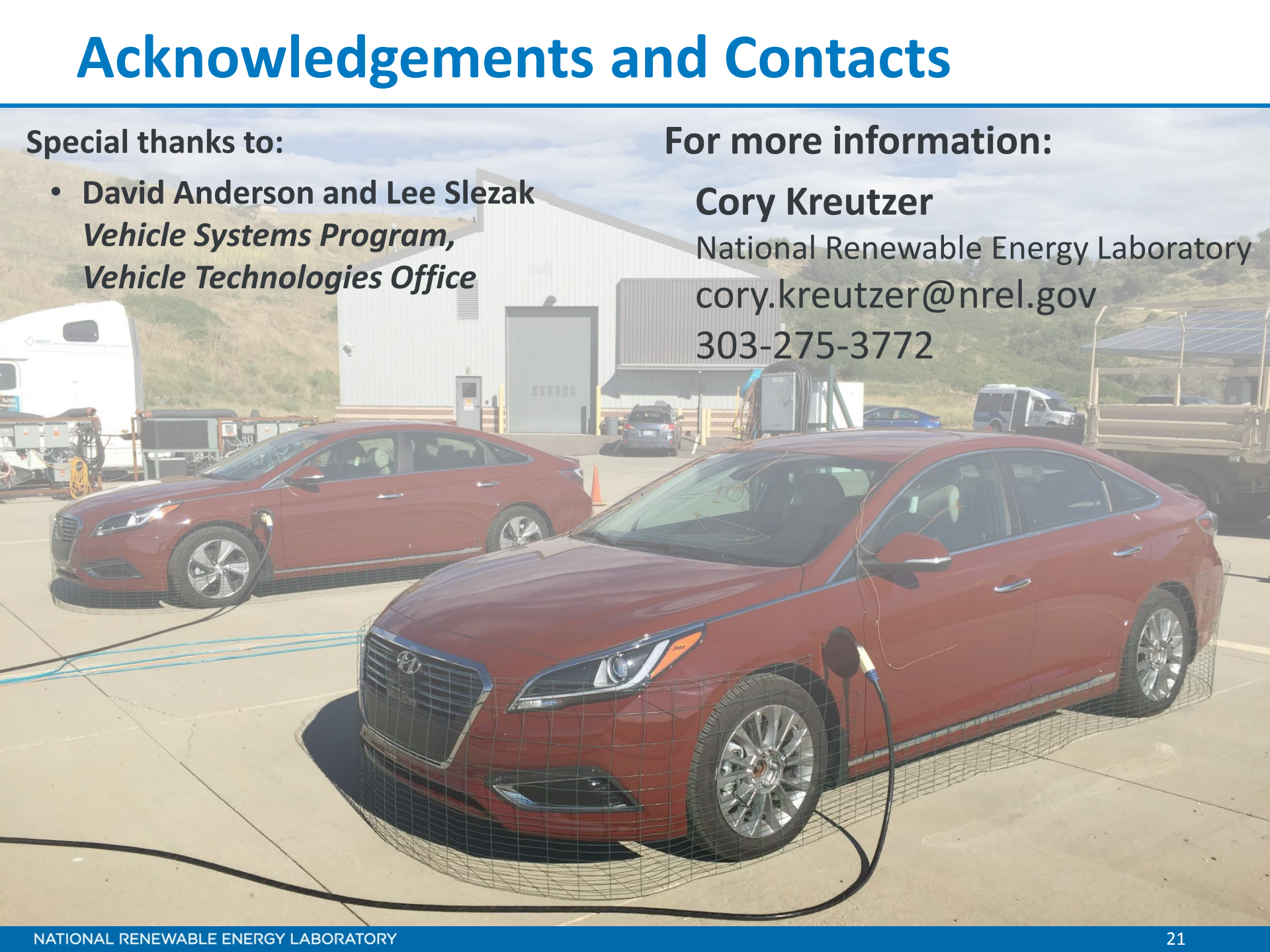
Acknowledgements and Contacts

Special thanks to:

- **David Anderson and Lee Slezak**
  Vehicle Systems Program,
  Vehicle Technologies Office

For more information:

Cory Kreutzer
National Renewable Energy Laboratory
cory.kreutzer@nrel.gov
303-275-3772



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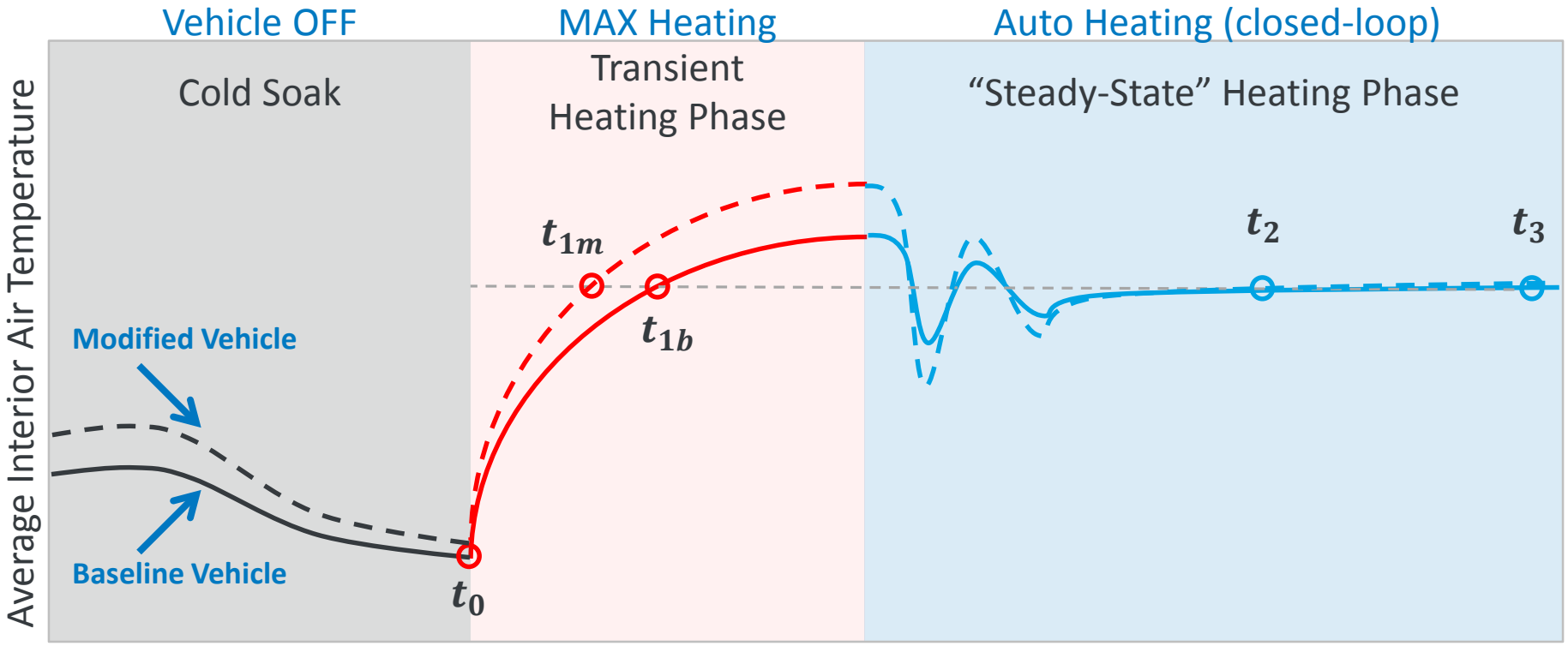
Technical Back-up Slides

Winter Heating Test Procedure

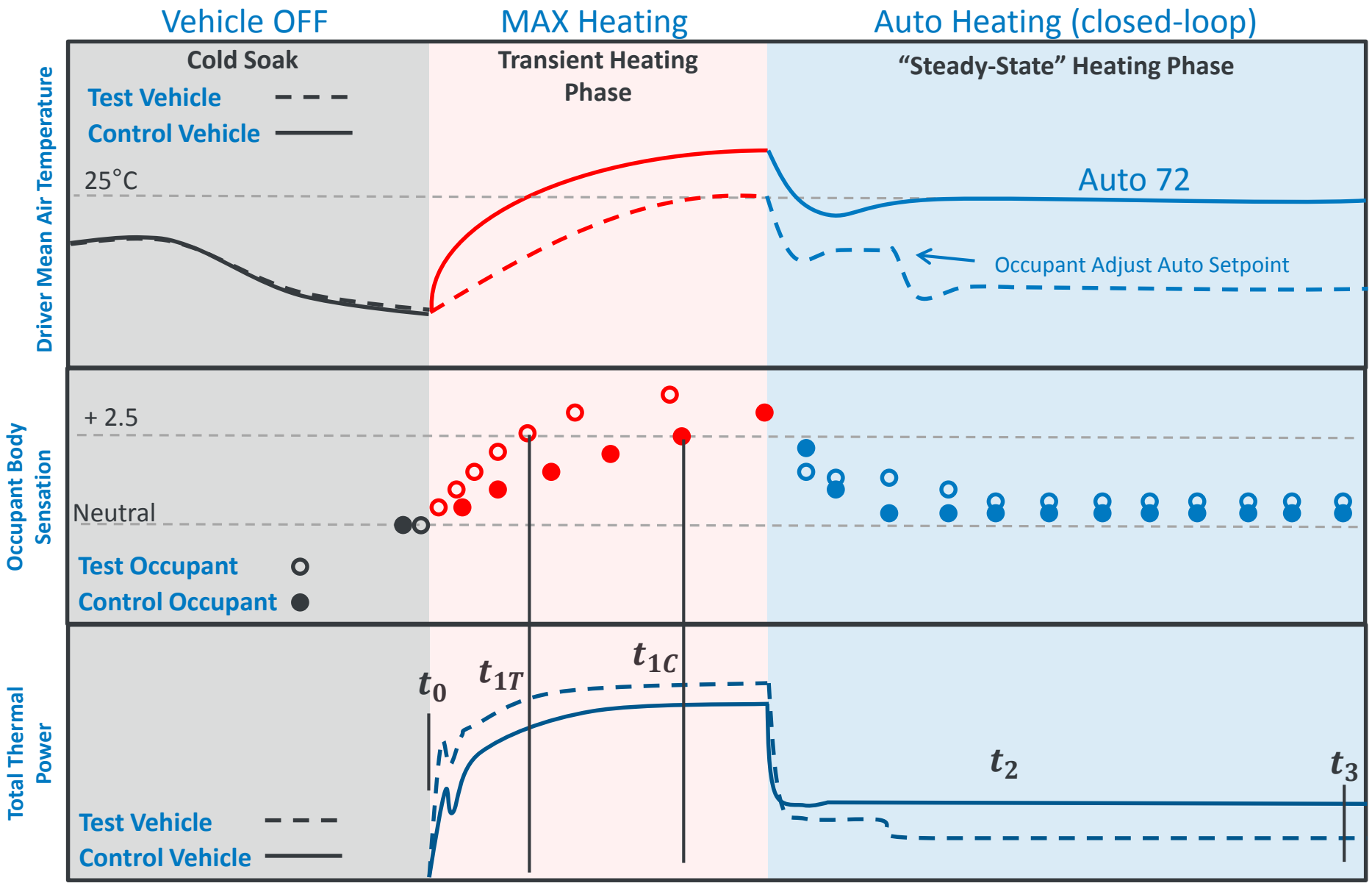
- Heating test method used for baseline and insulation performance testing



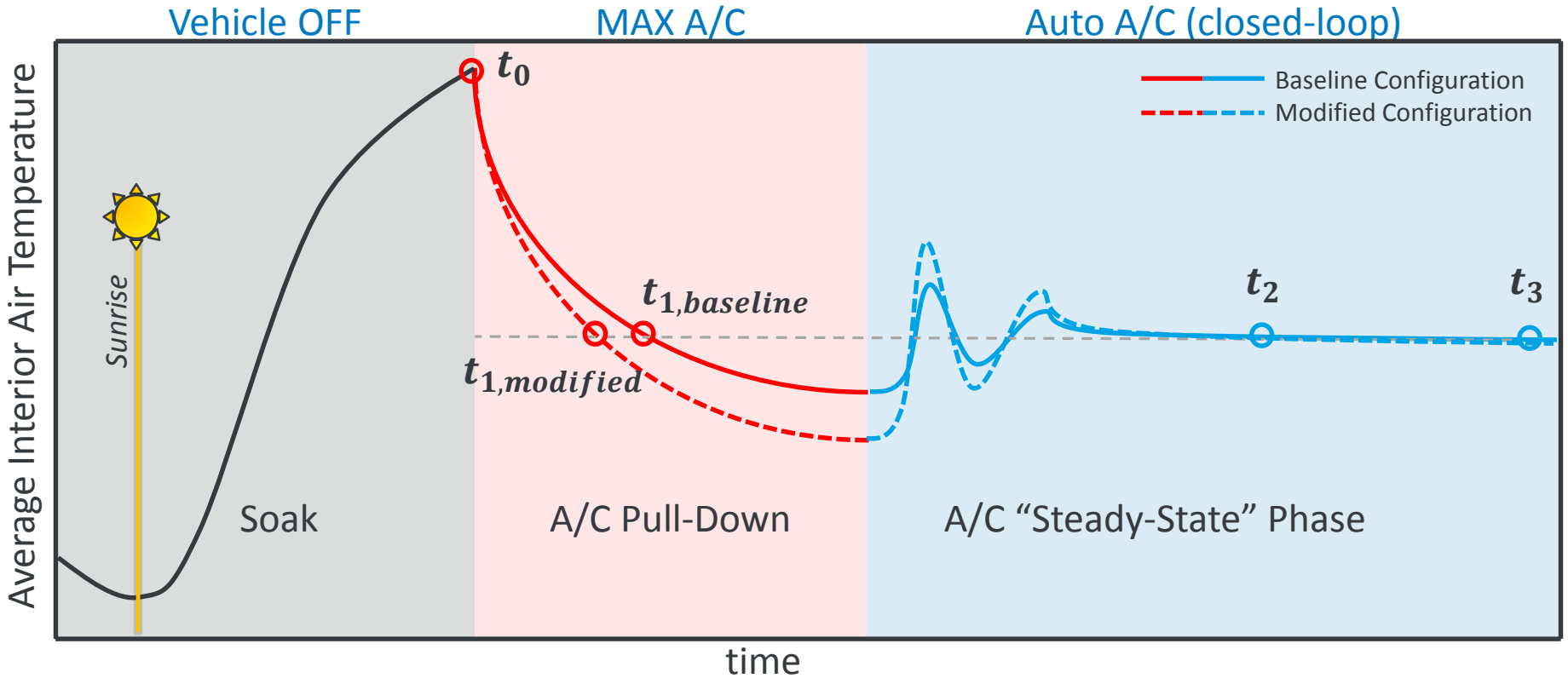
Baseline Vehicle:
Energy from $t_0 \rightarrow t_{1b}$
Modified Vehicle:
Energy from $t_0 \rightarrow t_{1m}$

Both Vehicles:
Energy from $t_2 \rightarrow t_3$

Heated Surfaces Test Procedure



Phase I Summer A/C Test Approach



- **Two-part A/C test method**
  - Pull-down and steady-state phases independently measured
- **Energy use during each test period integrated over specified time interval**
- **Method is intended to increase repeatability and isolate technology impact**