PERFORMANCE EVALUATION OF A THERMAL LOAD REDUCTION SYSTEM IN A HYUNDAI SONATA PHEV

Cory Kreutzer, John P. Rugh, Gene Titov
National Renewable Energy Laboratory

James Gallagher
Gentherm, Inc.

Matthew Scott
Hyundai America Technical Center, Inc.

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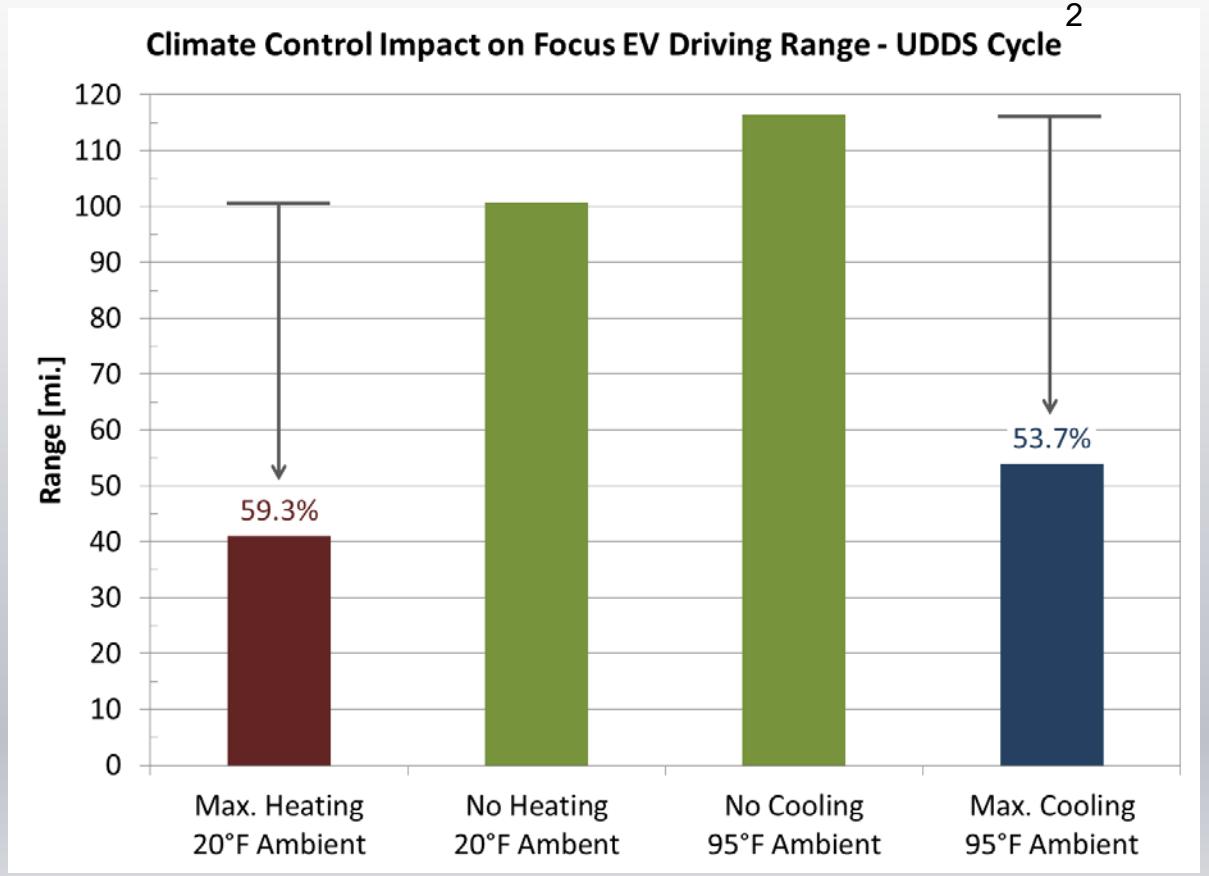
Improving Electric Vehicle Range to Increase Consumer Adoption

Annual U.S. Light-duty Fuel Use



1. *Data Source: EIA Annual Outlook 2014 http://www.eia.gov/forecasts/aeo/data.cfm*, accessed April 2015
2. *Data Source:* Argonne National Laboratory's Advanced Powertrain Research Facility

Potential Benefits of Climate Control Load Reduction

- Reducing climate control loads enables
  - Smaller, less expensive batteries
  - Smaller climate control components
  - Advanced climate control strategies

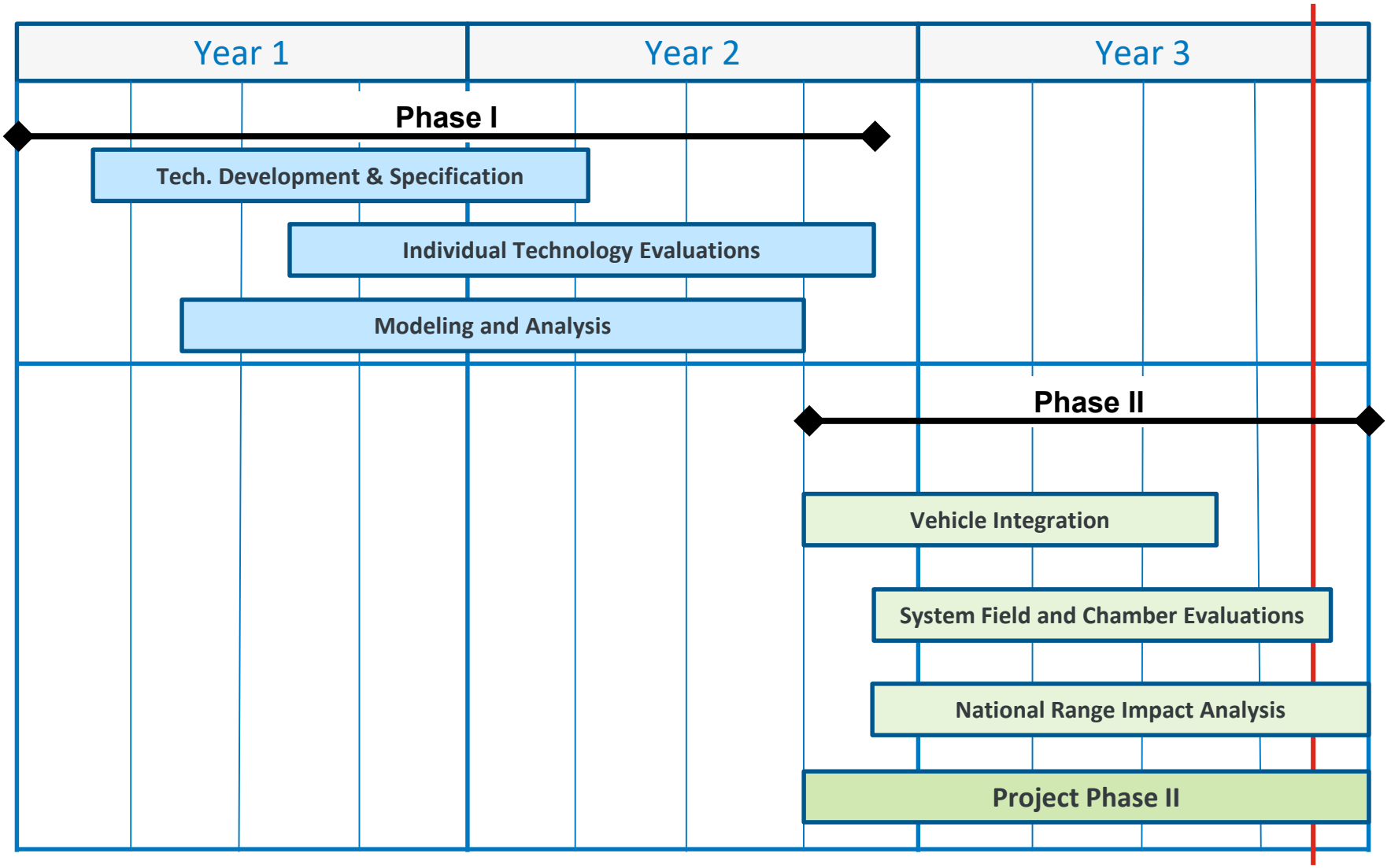
- Load reduction and advanced climate control design can positively impact occupant comfort
  - Faster time-to-comfort with less energy
- Load reduction system demonstration provides low risk, early data for OEMs

Thermal Load Reduction System Project Goal

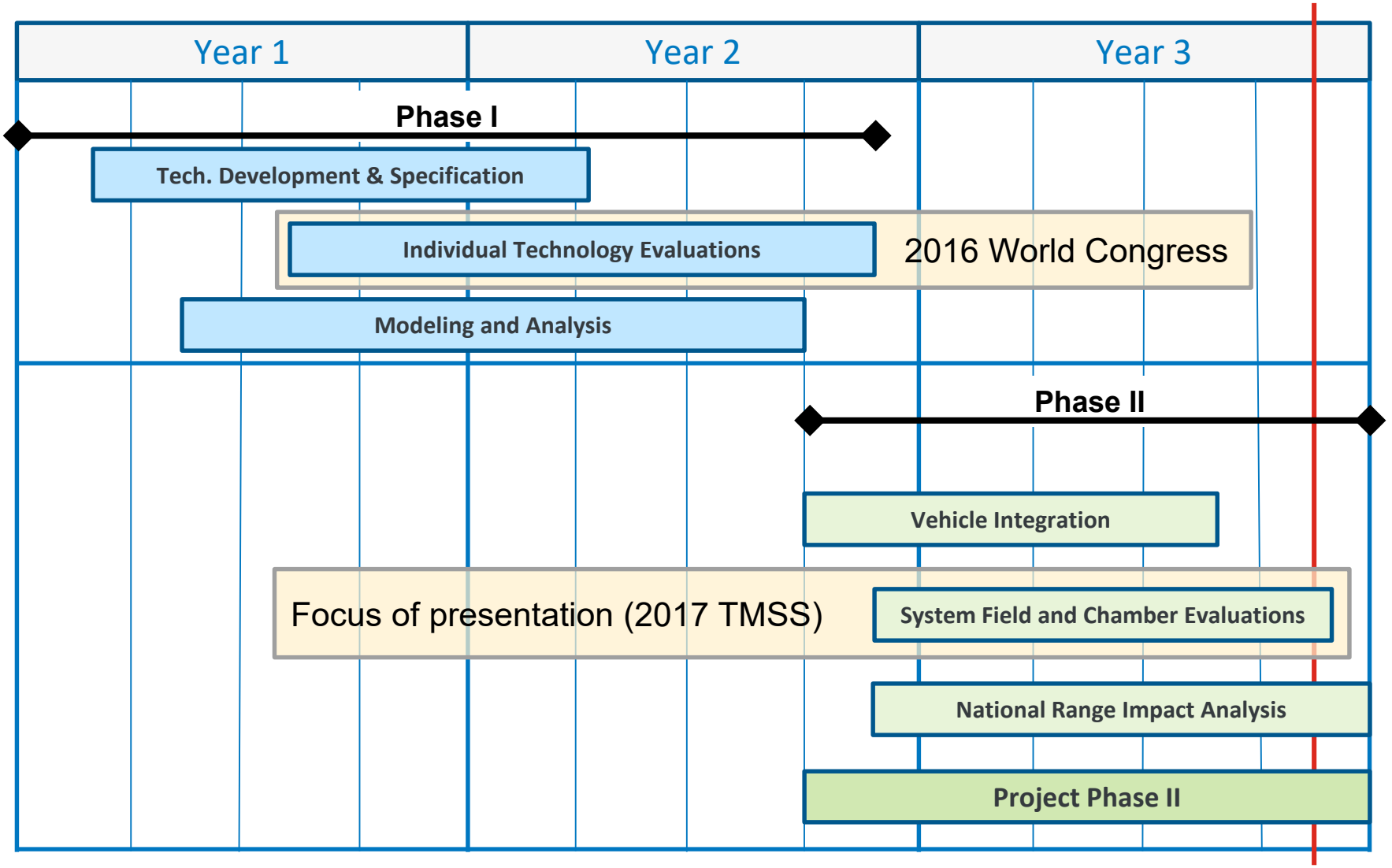
Increase grid-connected EDV range by 20% during operation of the climate control system over the standard vehicle configuration by reducing vehicle thermal loads

- 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

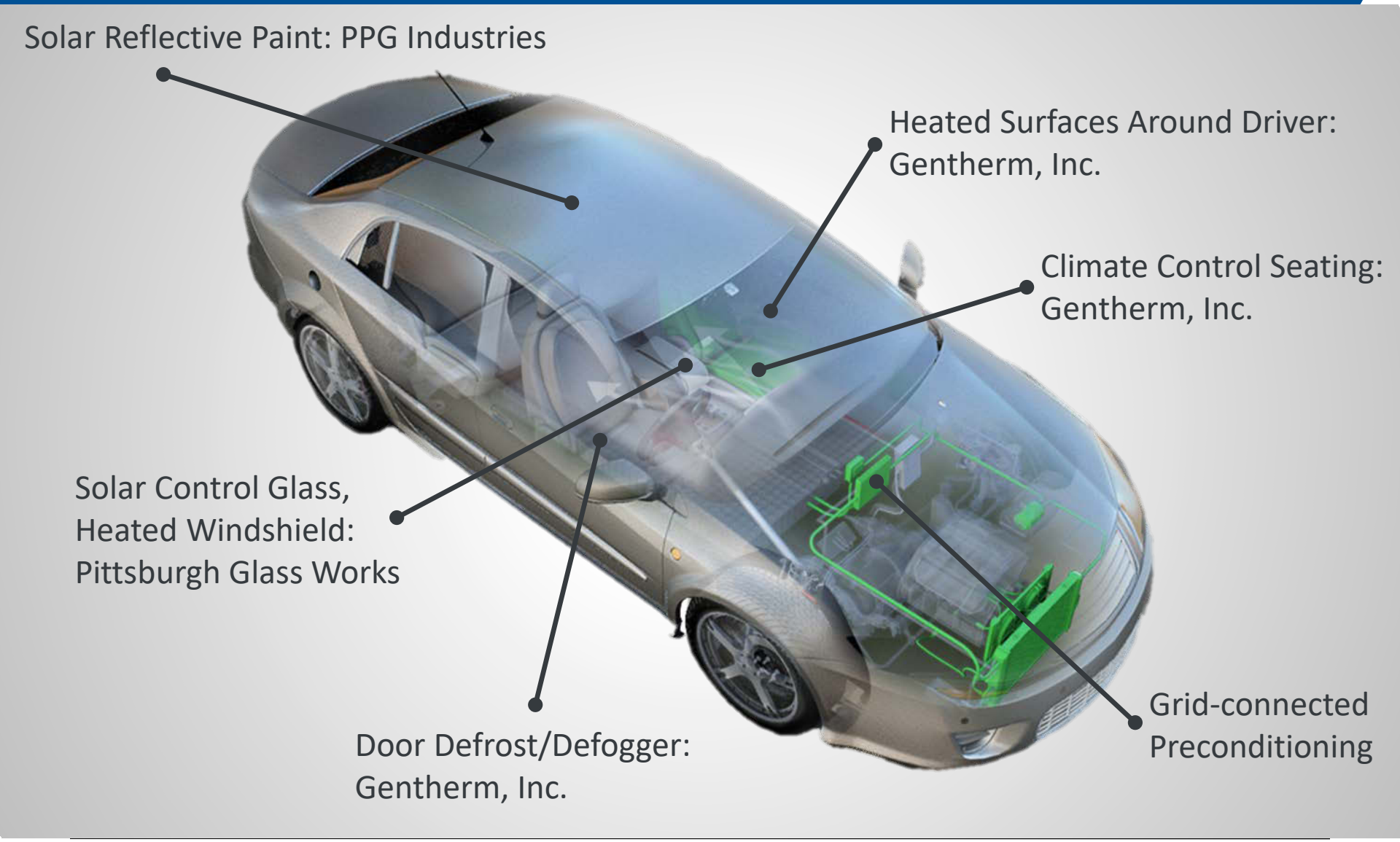
Approach: Full Project Timeline



Approach: Full Project Timeline



Approach: Technology Focus Areas for Phase II



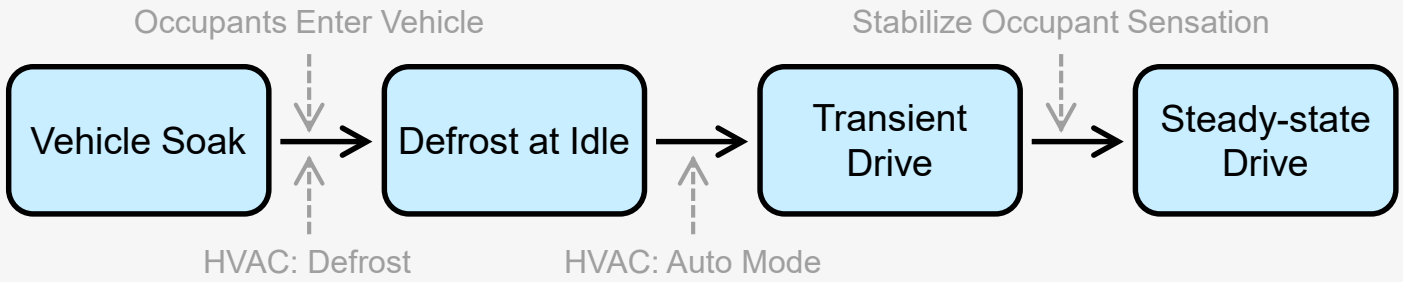
Approach: Phase II Cold Weather Field Evaluation

Location: Fairbanks, AK
Date: February, 2017

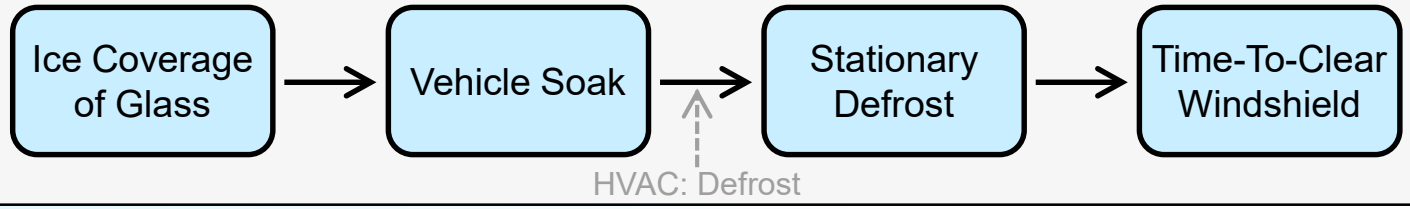
Vehicles
- Baseline Sonata PHEV
- Sonata PHEV modified with thermal load reduction package

Test Types:

Transient and steady-state combined drives



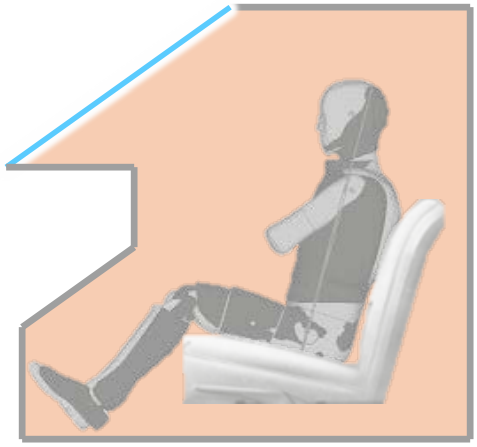
Stationary Defrost Testing



Results: Cold Weather Field Evaluation: Impact of Thermal Load Reduction Technologies

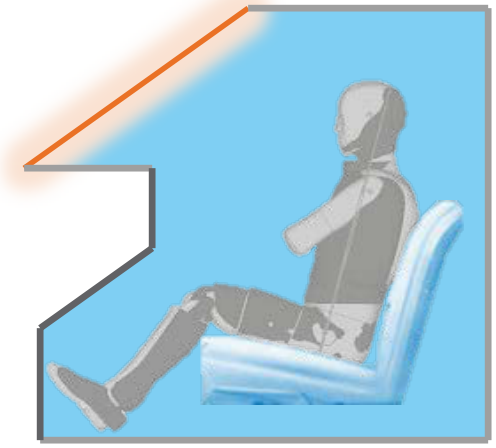
Standard Heating System

PTC Heater and Heater Core from Engine



Heated Windshield

Electrical Resistance



Transient Test Example (33 minutes)

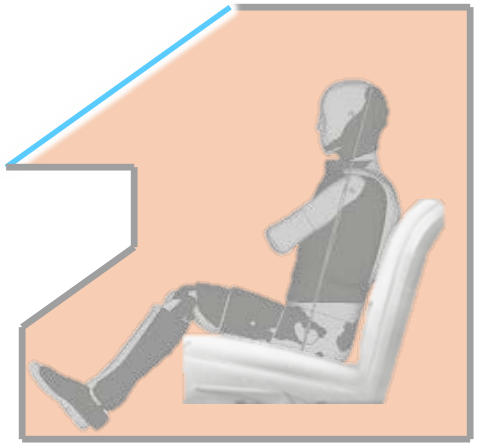
Technology	Power While On [W]	Duty Cycle [%]	Total Energy [kWh]
Heated Windshield	935	37.1	0.191

- Decoupled defogging/deicing from HVAC
- Reduces radiative heat loss from front of body

Results: Cold Weather Field Evaluation: Impact of Thermal Load Reduction Technologies

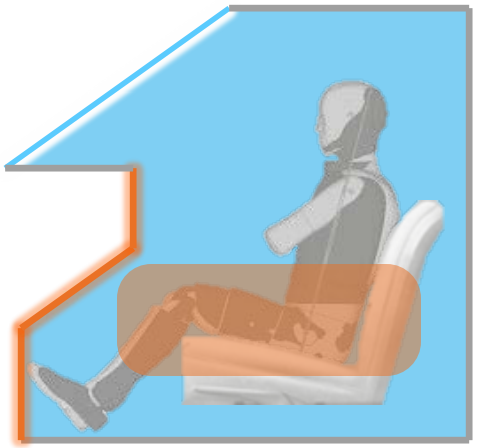
Standard Heating System

PTC Heater and Heater Core from Engine



Heated Surfaces

Electrical Resistance



Transient Test Example (33 minutes)

Technology	Power While On [W]	Duty Cycle [%]	Total Energy [kWh]
Heated Surfaces (driver & passenger)	287	28.5	0.045

- Contact and non-contact heating of extremities
- Reduces radiative heat loss from front of body

Results: Cold Weather Field Evaluation: Impact of Thermal Load Reduction Technologies

Standard Heating System

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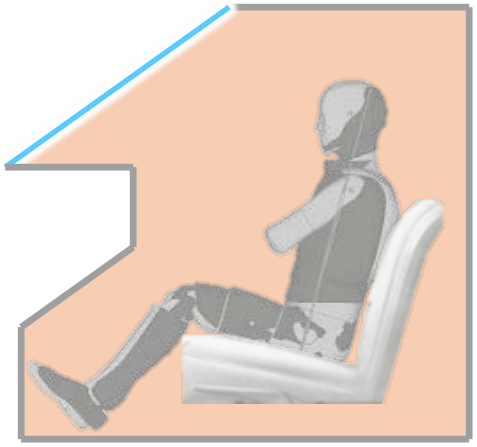
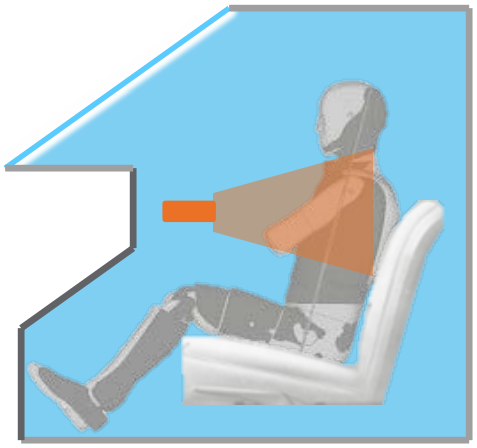


Door Demisters

Electrical Resistance



Transient Test Example (33 minutes)

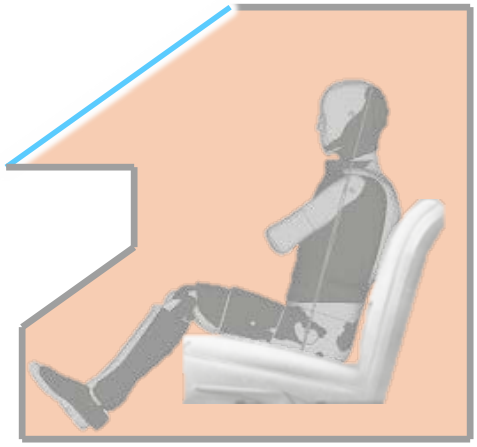
Technology	Power While On [W]	Duty Cycle [%]	Total Energy [kWh]
Door Demisters	166	82.1	0.075

- Provides heat source for shoulder, increases local breath level air temperature
- Decouples defogging from HVAC

Results: Cold Weather Field Evaluation: Impact of Thermal Load Reduction Technologies

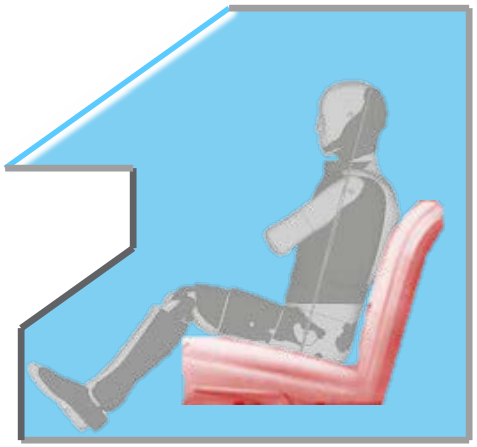
Standard Heating System

PTC Heater and Heater Core from Engine



Heated Seats

Electrical Resistance



Transient Test Example (33 minutes)

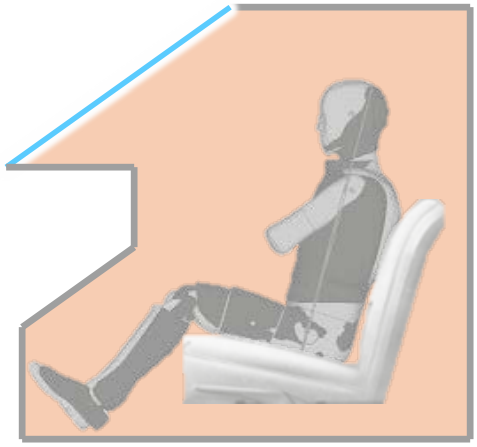
Technology	Power While On [W]	Duty Cycle [%]	Total Energy [kWh]
Heated Seats (driver & passenger)	128	83.8	0.059

- Large contribution to occupant comfort combined with low power demand
- Fast response technology during warmup

Results: Cold Weather Field Evaluation: Impact of Thermal Load Reduction Technologies

Standard Heating System

PTC Heater and Heater Core from Engine

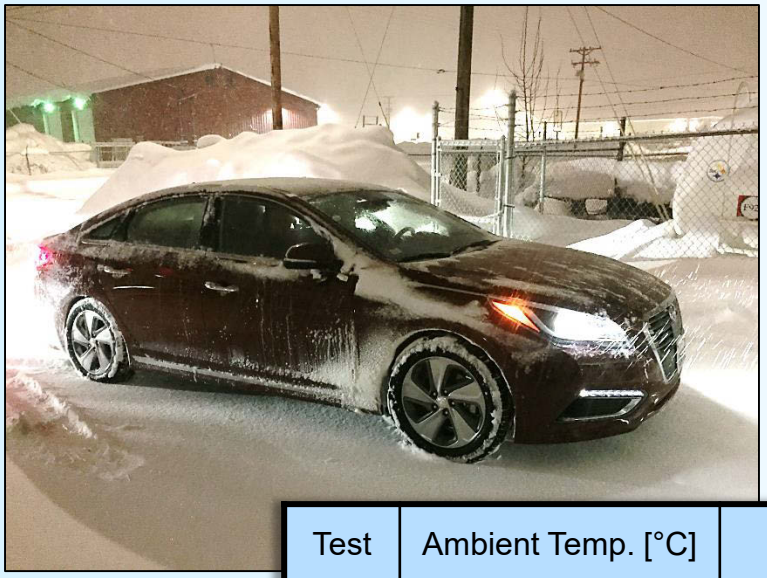


Thermal Load Reduction System

Transient Test Example (33 minutes)

Technology	Power While On [W]	Duty Cycle [%]	Total Energy [kWh]
Heated Windshield	935	37.1	0.191
Heated Surfaces	287	28.5	0.045
Door Demisters	166	82.1	0.075
Heated Seats	128	83.8	0.059
Total			0.37

Results: Cold Weather Field Evaluation: Transient Drives

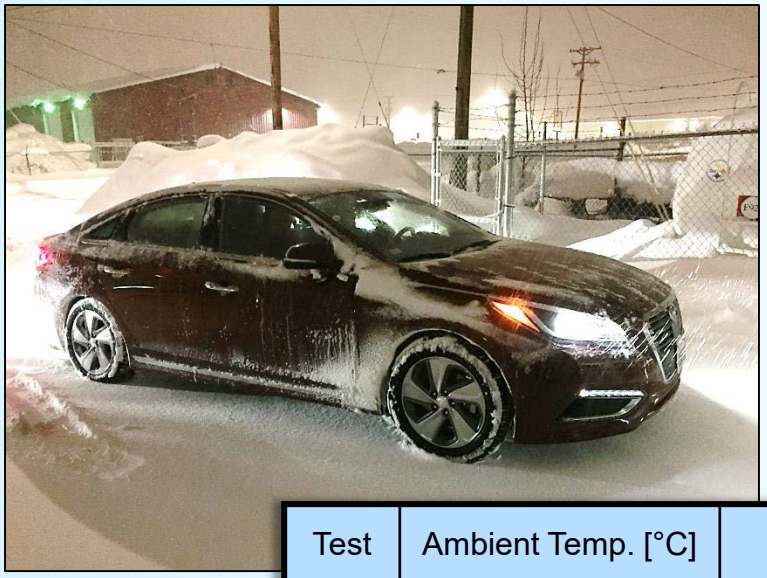


Baseline: Baseline Sonata PHEV
Thermal Package: Sonata PHEV modified with thermal load reduction package

Thermal Package
- HVAC auto temperature setpoint adjusted as necessary throughout test
- Average of 40% improvement in time-to-comfort compared to baseline

Test	Ambient Temp. [°C]	Vehicle	Engine Off [%]	Improvement [%]
1	-2	Baseline	11.9	
		Thermal Package	50.9	39.0
2	-8	Baseline	0	
		Thermal Package	27.5	27.5
3	-12	Baseline	0	
		Thermal Package	26.9	26.9
Average		Baseline	4	
		Thermal Package	35.1	31.1

Results: Cold Weather Field Evaluation: Steady-State Drives



Baseline: Baseline Sonata PHEV
Thermal Package: Sonata PHEV modified with thermal load reduction package

Thermal Package
- HVAC auto temperature setpoint adjusted as necessary throughout test

Test	Ambient Temp. [°C]	Vehicle	Engine Off [%]	Improvement [%]
1	-2	Baseline	55.9	
		Thermal Package	75.7	19.9
2	-8	Baseline	39.8	
		Thermal Package	69.5	29.7
3	-12	Baseline	46.8	
		Thermal Package	54.1	23.0
Average		Baseline	49.3	
		Thermal Package	72.3	24.2

Results – Cold Weather Field Testing
Defrost Performance

Baseline Vehicle Max Heat Max Blower Defrost Mode	Ambient Temperature: -6C	Modified Vehicle HVAC OFF Heated WS ON Door Demisters ON
	Start of Test	
	Time = 6 minutes	
	Time = 19 minutes	

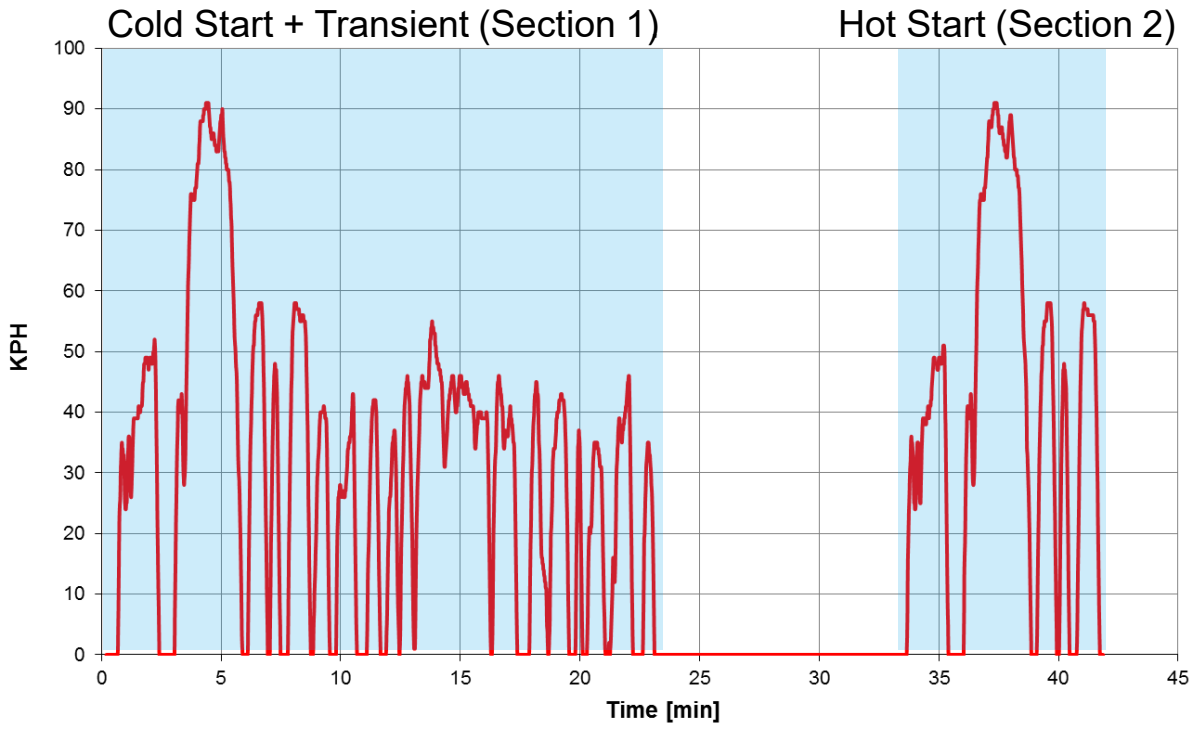
Energy Comparison

Vehicle	Total Energy [kWh]
Baseline	2.60
Modified	0.10

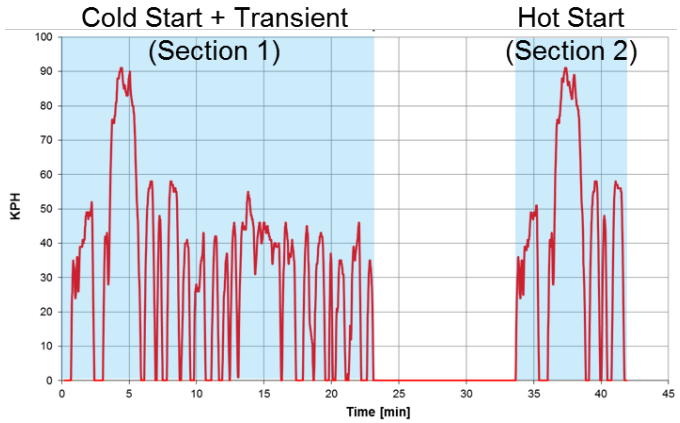
Approach: Cold Chamber Evaluation

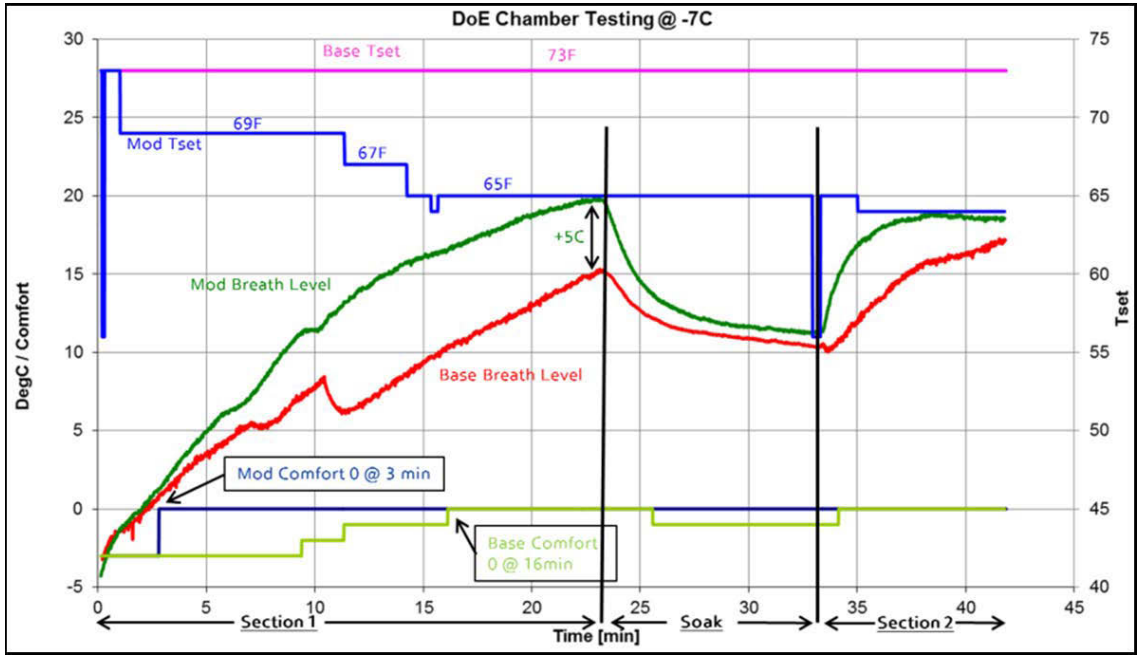
Cold Chamber Evaluation

- EPA FTP driving schedule was used
- -7°C Chamber and vehicle soak temperature
- Baseline and modified vehicles both charged to 100% SOC
- Baseline and modified vehicles HVAC: Auto mode
  - Modified vehicle T setpoint changed to compliment additional technologies

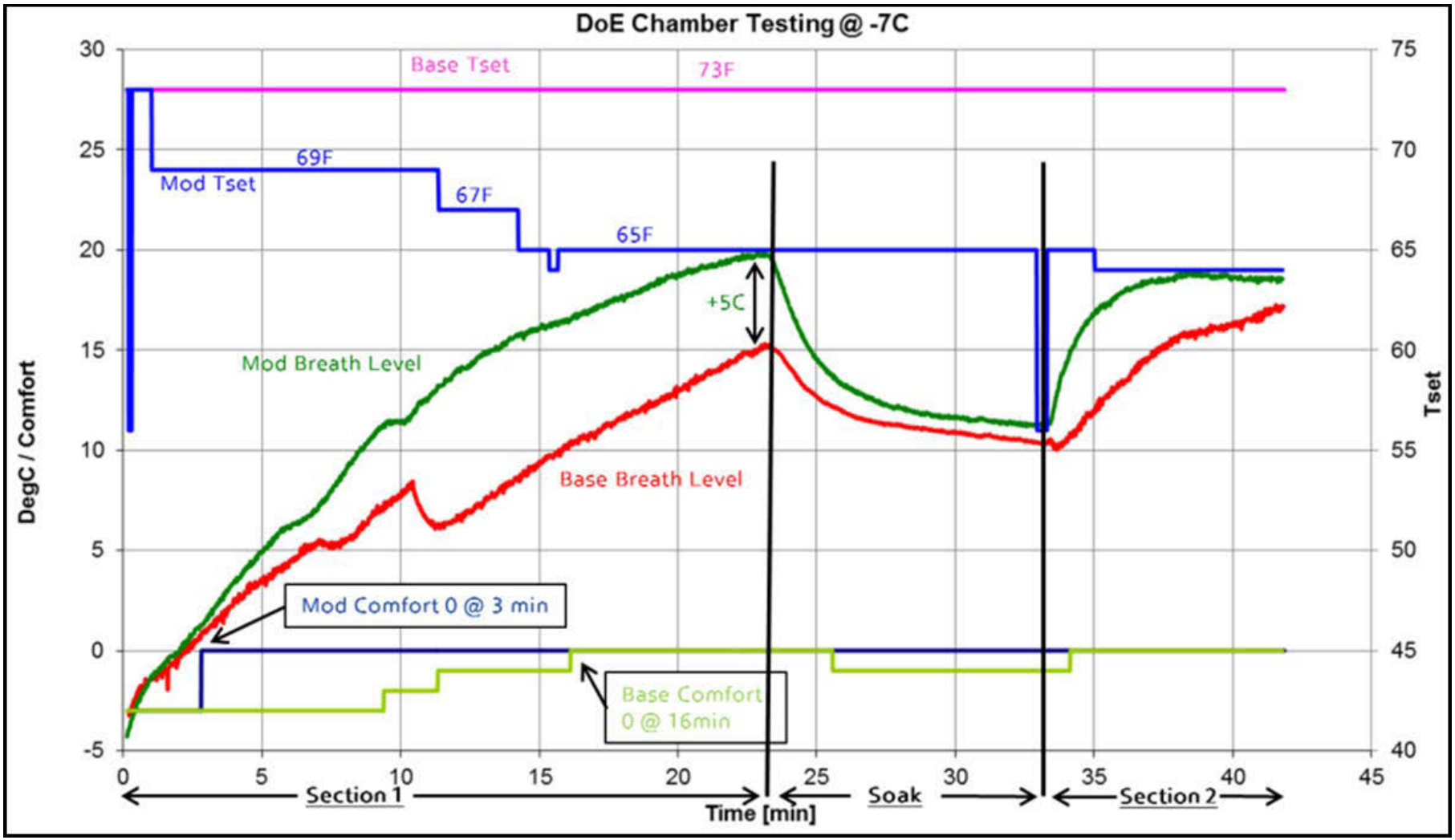


Results – Cold Chamber Evaluation





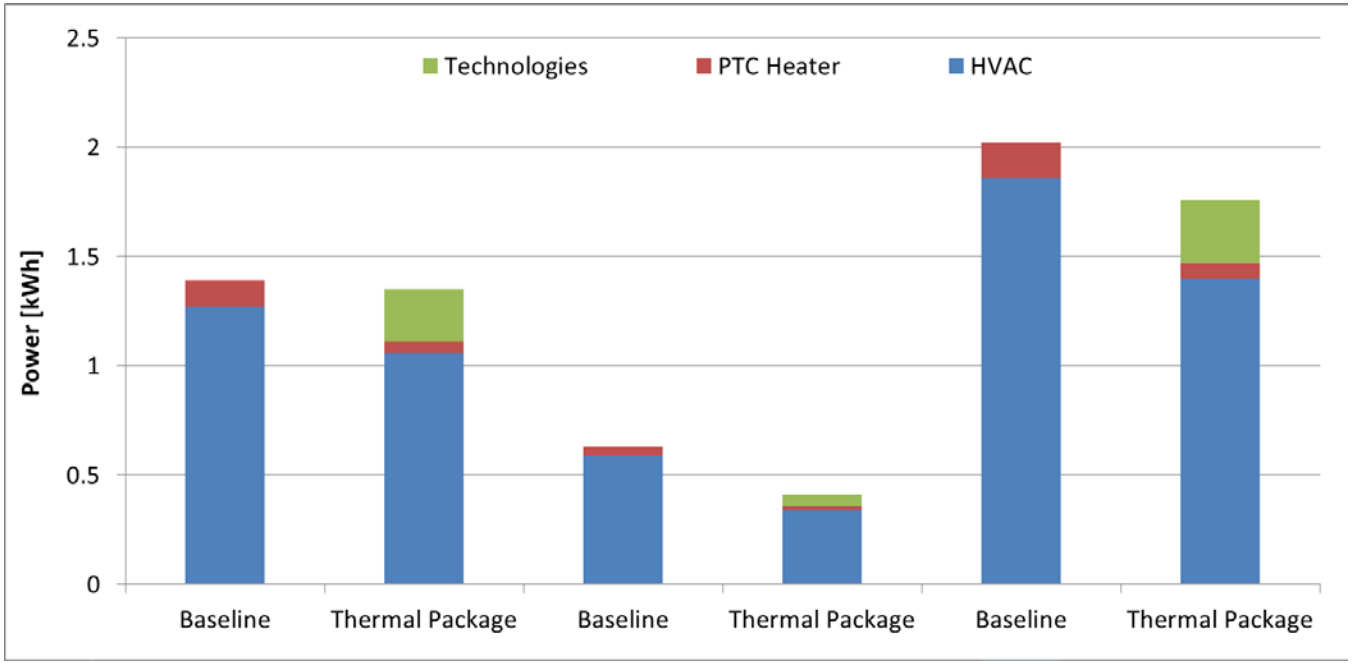
Results – Cold Chamber Evaluation



Results – Cold Chamber Evaluation

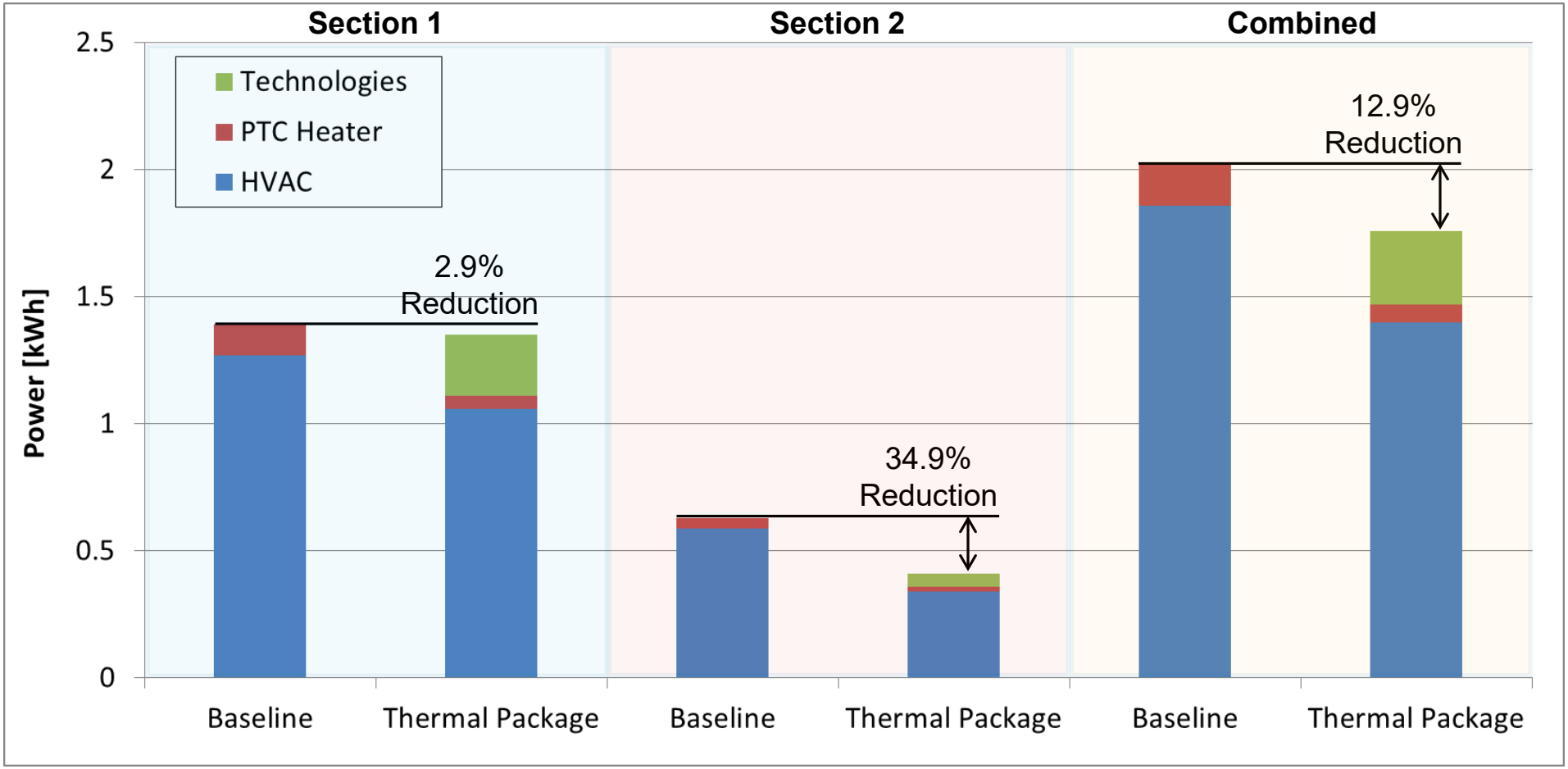
- Thermal package used 12.9% less power than the baseline
- 8.9% improvement in fuel economy for the test cycle due to reduced engine on-time

	Section 1		Section 2		Combined	
Energy Source [kWh]	Baseline	Thermal Package	Baseline	Thermal Package	Baseline	Thermal Package
HVAC	1.27	1.06	0.59	0.34	1.86	1.40
PTC Heater	0.12	0.05	0.04	0.02	0.16	0.07
Technologies	0	0.24	0	0.05	0	0.29



Results – Cold Chamber Evaluation

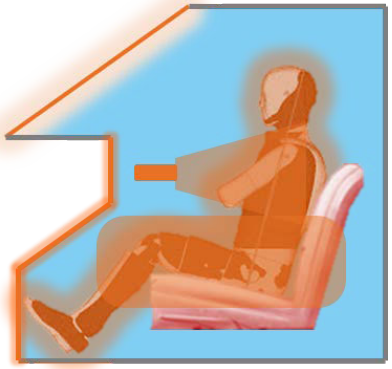
- 8.9% improvement in fuel economy for the test cycle due to reduced engine on-time



Summary / Conclusions

Cold Weather Field Evaluation

Demonstrated the use of combined technologies for occupant comfort and load reduction



Transient Performance

- 40% improvement in time-to-comfort
- Average of 31.1% improvement in engine off time

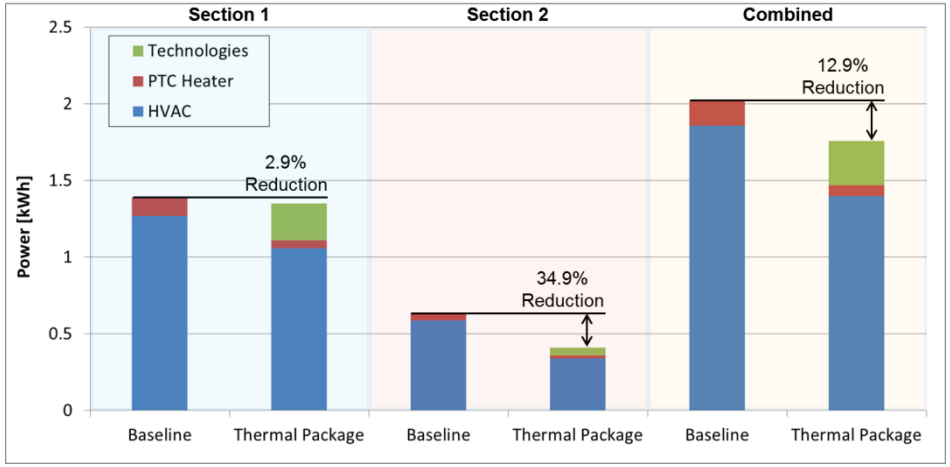
Steady-State Performance

- Average of 24.2% improvement in engine off time

Defrost

- 68% improvement in time-to-clear glass
- 0.1kWh compared to 2.6kWh for baseline

Cold Chamber Evaluation



- Quantified performance of thermal load reduction system over FTP driving schedule (cold start and transient, hot start)
- 12.9% reduction in heating power over baseline
- 8.9% improvement in fuel economy for the test cycle due to reduced engine on-time
- EV range improvement will be determined through national-level analysis process and reported in future SAE paper and presentation

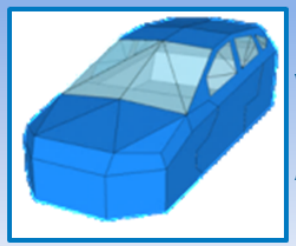
Next Steps: National Range Estimation for Technologies and System Package

Vehicle Configurations

Baseline Vehicle

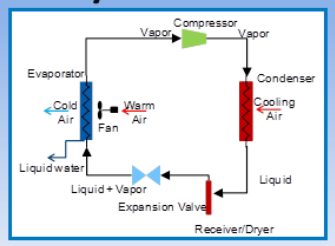
Thermal Load Reduction Vehicle

CoolCalc Cabin Model



Cabin Thermal Load

CoolSim A/C Model

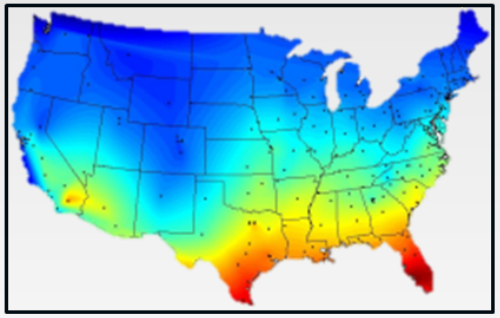


Accessory Load

FASTSim Vehicle Model

Vehicle Range

Impact of Technologies on National EV Climate Control Range



Driver Behaviors

Weather and Vehicle Registrations

Acknowledgements and Contacts

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U.S. Department of Energy

For more information:

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

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