NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Commercial Vehicle Thermal Load Reduction and VTCab – Rapid HVAC Load Estimation Tool


[1]

U.S. Department of Energy
Annual Merit Review

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Project ID #VS075

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Overview

Timeline

- **Project Start Date: FY16**
- **Project End Date: FY18**
- **Percent Complete: 16%**

Barriers

- **Risk Aversion** – *Industry lacks key performance data on* heating, ventilation, and air conditioning (*HVAC) loads and commercial vehicle thermal load reduction technologies.*
- **Cost** – *Fleets operate on small profit margins and are sensitive to purchase costs of equipment.*
- **Computational Models, Design, and Simulation Methodologies** – *Industry lacks adequate commercial vehicle thermal load models.*

Budget

Total Project Funding:

(Commercial Vehicle Thermal Load Reduction /VTCab):

- **Funding for FY16: $250K/$175K**

Partners

- Collaborations
  - Volvo Trucks
  - Daimler Trucks
  - Kenworth (PACCAR)
  - PPG Industries
  - Aearo Technologies LLC, a 3M Company
  - Developing new partnerships in other vocations
- Project lead: National Renewable Energy Laboratory (NREL)

Relevance – Project Description

THE CHALLENGE

- **Heavy-vehicle energy use is the fastest growing transportation sector**
- **Commercial vehicle idling contributes to our dependence on foreign oil**
  - 2 Billion gallons used for workday idling[1]
  - 667 Million gallons of diesel fuel used annually for long-haul truck rest period idling[1]
- **Increased idling regulation at the local, state, and national level [2]**
- **Thermal management design is critical for advanced commercial-vehicle performance**
  - Fuel penalty for A/C on hybrid buses can be 17%-27%[3]

- **Large uncertainty with technology payback period and effectiveness**
- **Understanding thermal solutions over different seasons and modes of operation is important to effective vehicle design**

1. Gaines, L., Vyas, A., and Anderson, J., "Estimation of Fuel Use by Idling Commercial Trucks," 85th Annual Meeting of the Transportation Research Board, D.C., Paper No. 06-2567, January 22-26, 2006.
2. Roeth, M., Kircher, D., Smith, J., and Swim, R., "Barriers to the Increased Adoption of Fuel Efficiency Technologies in the North American On-Road Freight Sector," Report for the International Council for Clean Transportation, NACFE, July 2013.
3. Muncrief, R., et al, "Impact of Auxiliary Loads on Fuel Economy and Emissions in Transit Bus Application," SAE World Congress, 2012.

Relevance – Project Description

THE OPPORTUNITY

- Improved vehicle thermal management will increase vehicle efficiency
- Reducing stationary thermal loads will enable idle-reduction technologies
- Fleets are economically motivated by a 3-year or better payback period
- Effective solutions are needed to meet regulations
- Fuel use and payback period quantification aid manufacturers in cost-benefit decisions and reduce risk to fleets

ALIGNMENT WITH DOE

- Vehicle Systems key goals for 2011–2015 Program Plan:
  - *Expand activities to develop and integrate technologies that address ... **auxiliary load reduction**, and **idle reduction** to greatly improve commercial vehicle efficiency*
- EERE 2016-2020 Strategic Plan:
  - *Develop technologies to reduce vehicle energy use…vehicle systems (e.g., ..interior ventilation, and air conditioning)*
- 21st Century Truck Partnership:
  - *NAS 21CTP review recommended a goal to reduce energy required over a drive cycle for non-engine thermal loads by 50%*

Relevance – Project Goals

- **Identify commercial vehicle parasitic loads that contribute to at least 2% of fuel use or range and demonstrate solutions with a 3-year or better payback period**
  - Demonstrate at least a 30% reduction in long-haul truck idle climate control loads with a 3-year or better payback period.
  - Apply tools and methods to evaluate other commercial vehicle opportunities including buses, shuttle vans, worksite trucks, etc.
- **Develop modeling tools and experimental methods to improve quantification of thermal load reduction solutions, thereby reducing the risk of adopting new technologies**

Milestones: Commercial Vehicle Thermal Load Reduction

FY 2016				FY 2017				FY 2018			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4

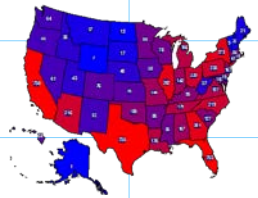
Screen commercial vehicle applications and build partnerships for promising applications

Test promising commercial vehicle applications, build models

M1

HVAC load reduction, complete next steps for long-haul trucks

Perform national-level fuel use estimation and payback period analysis



M2

Demonstrate load reduction and provide payback period estimation

M3

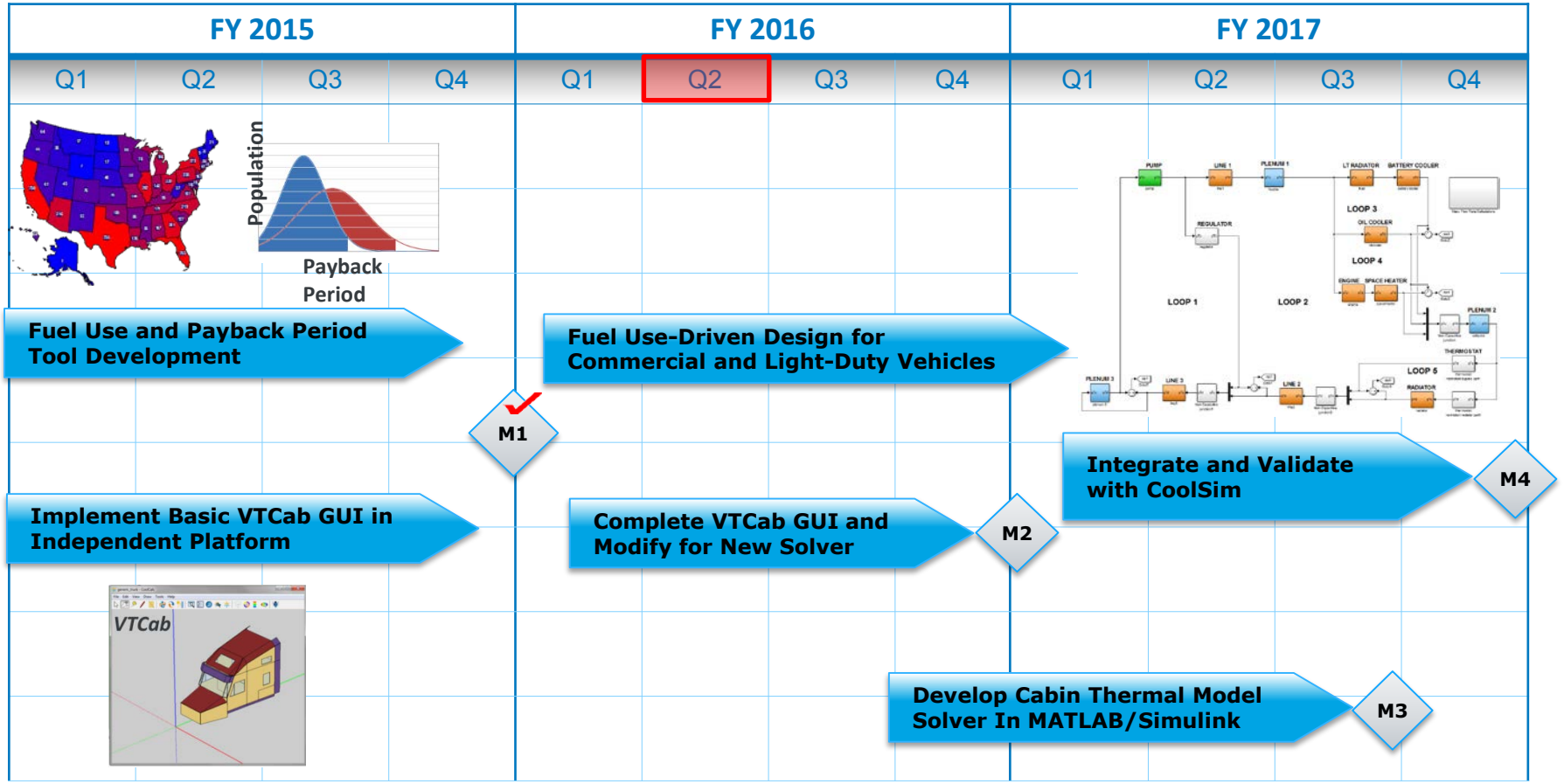
Milestones:

M1. Identify commercial vehicle parasitic loads that contribute to at least 2% of fuel use or range

M2. Use testing and modeling methods to research promising solution methods for commercial vehicles. Measure the impact of load reduction technologies.

M3. Model regional and national-level fuel use impacts. Measure the impact of improved configurations. Compare payback period to 3-year target.

VTCab (Vehicle Thermal Cabin) Milestones



Milestones:

M1. A. Work with industry partners to improve code to meet their needs and demonstrate fuel use, payback period-driven design. B. Demonstrate VTCab environment with basic capabilities.

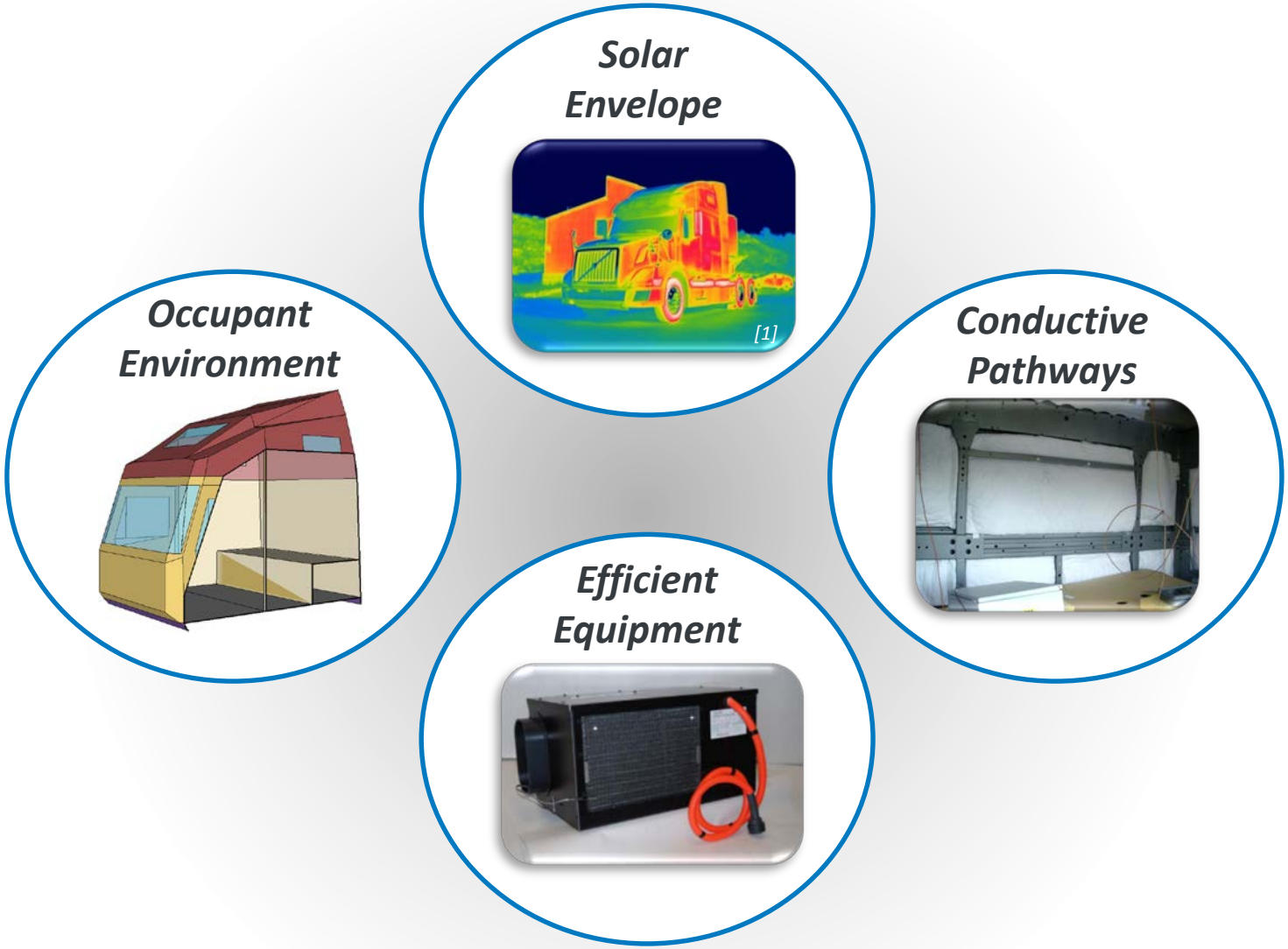
M2. Complete VTCab GUI with full set of capabilities. Apply the tool to project with partners.

M3. Develop a cabin thermal model solver in the MATLAB/Simulink environment for improved model capabilities including compatibility with CoolSim, NREL's detailed thermal system modeling tool in Simulink

M4. Integrate and validate cabin model in CoolSim and release updated program.

Approach – Overall Strategy

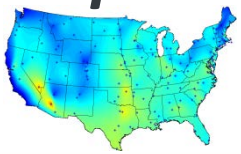
Technology Focus Areas



Approach – Overall Strategy

Modeling

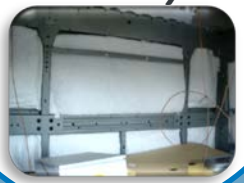
Impact



Solar Envelope

Occupant Environment

Conductive Pathways

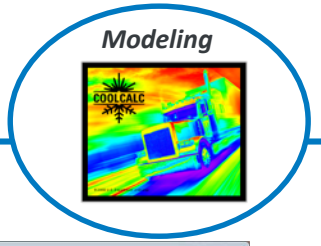


Efficient Equipment

Testing

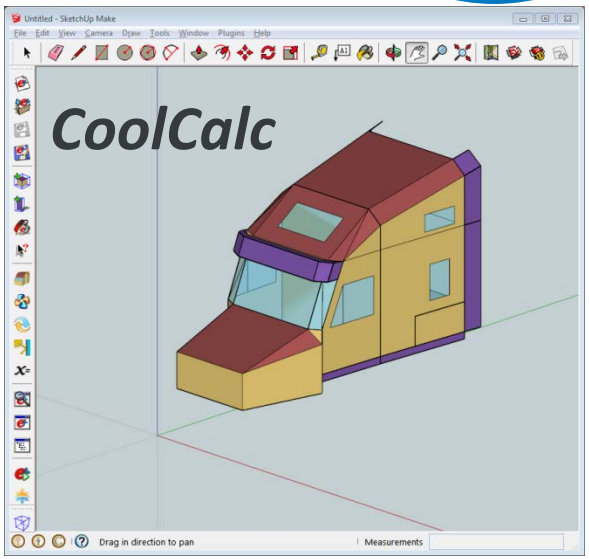
Industry Collaboration

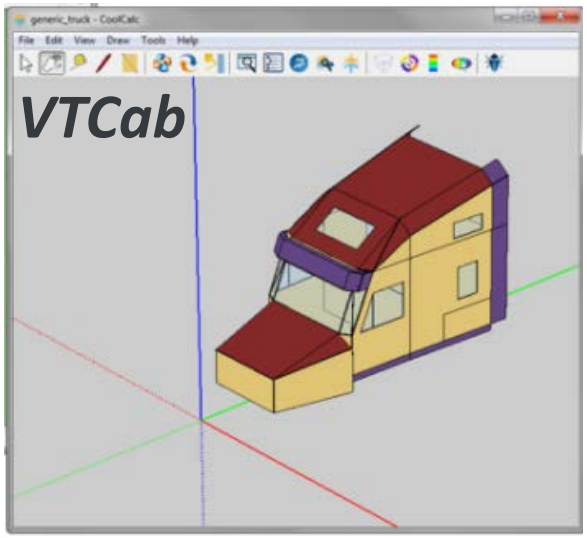
VTCab: Standalone Version of CoolCalc



Existing Limitations of CoolCalc

- Dependence on SketchUp interface and updates
- Dependence on EnergyPlus thermal solver
- Three-component installation process



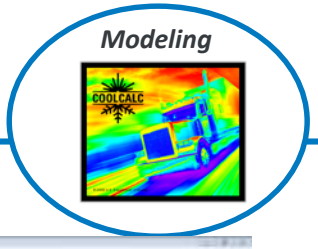


Advantages of VTCab over CoolCalc

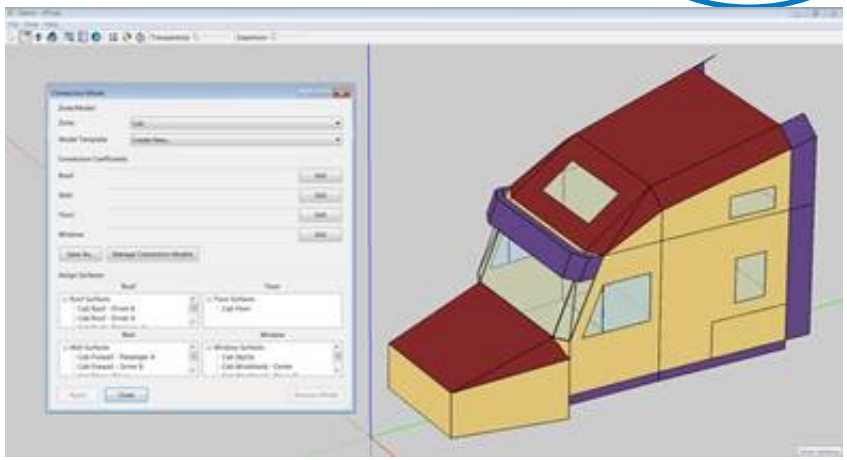
- Standalone execution
- Additional programming flexibility
- Model-specific tools only
- Bundle with EnergyPlus into one installer
- Ability to move to MATLAB/Simulink solver

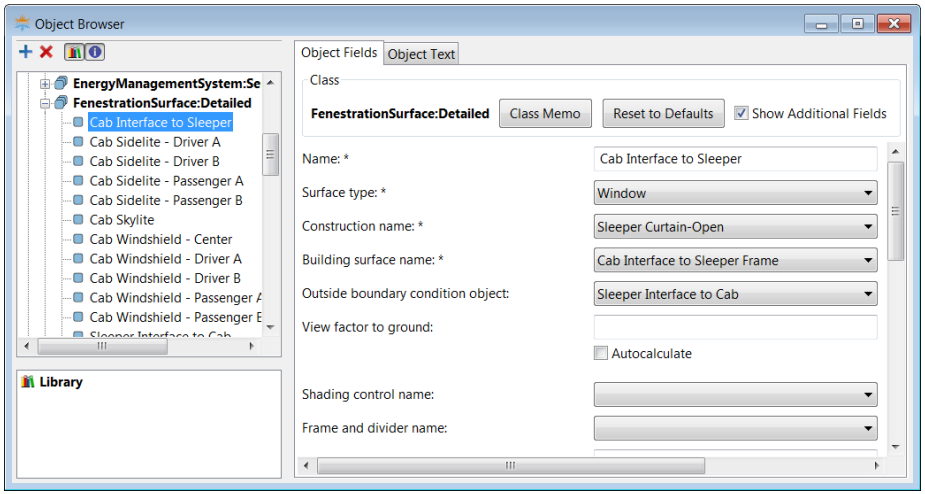
Accomplishments: VTCab Development

Beta release in March, basic modeling capabilities



- Improved importing (COLLADA files) to maintain sub-surfaces
- Convection model GUI, which allows application of custom convection models to the various interior surface groups: floor, walls, windows, and roof
- Zone and Construction Painters, which allow easy application of the properties to surfaces
- Parametric variables, which allow users to sweep values for one or more variables
- Updated documentation
- Fixed bugs, improving robustness





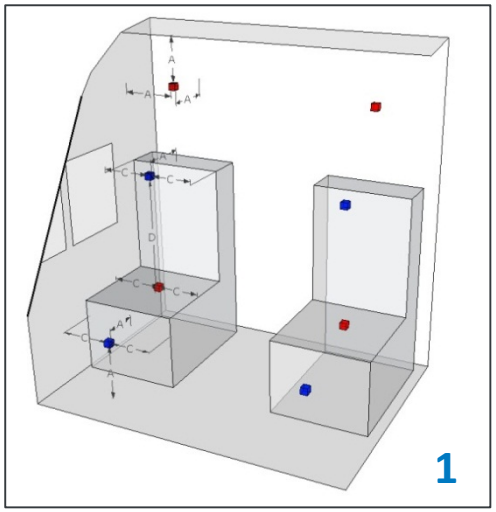
Complete Cab Solution

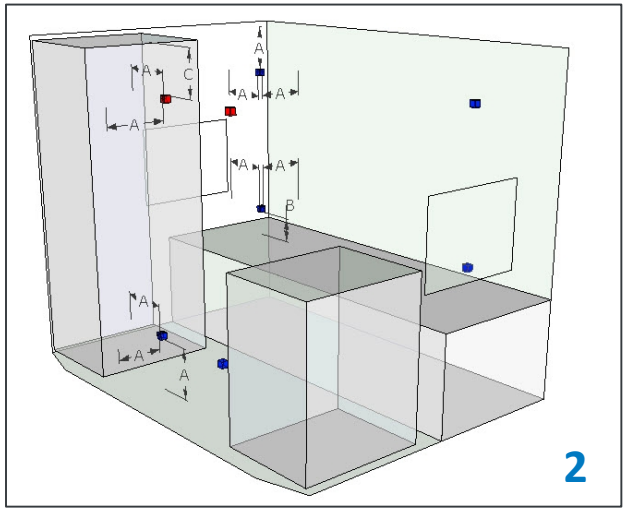
	Baseline	Complete-Cab Package	Complete-Cab Plus Package
Paint	National Average Solar-Color	Ultra-White	Ultra-White
Curtains	Stock OEM	Advanced	Advanced
Insulation	Stock OEM	Advanced Package	Advanced Plus

- Ultra-White paint: solar weighted reflectivity of 0.86
- Curtain and shades: NREL designed and fabricated prototype
- Insulation: Thinsulate with a combination of one- and two-inch-thick blanket with a nominal thermal conductivity between 0.03 and 0.05 W/m-K

Experimental Setup

- Test truck, test “buck” cab, control “buck” cab
  - South-facing vehicles
  - Buck firewall shade cloths
- Local weather station at test site
  - Solar, wind, ambient temperature, pressure, and RH.
- Dometic A/C Systems: 2,050 W (7,000 Btu/hr)
  - Set points of 22.2°C (72°F)



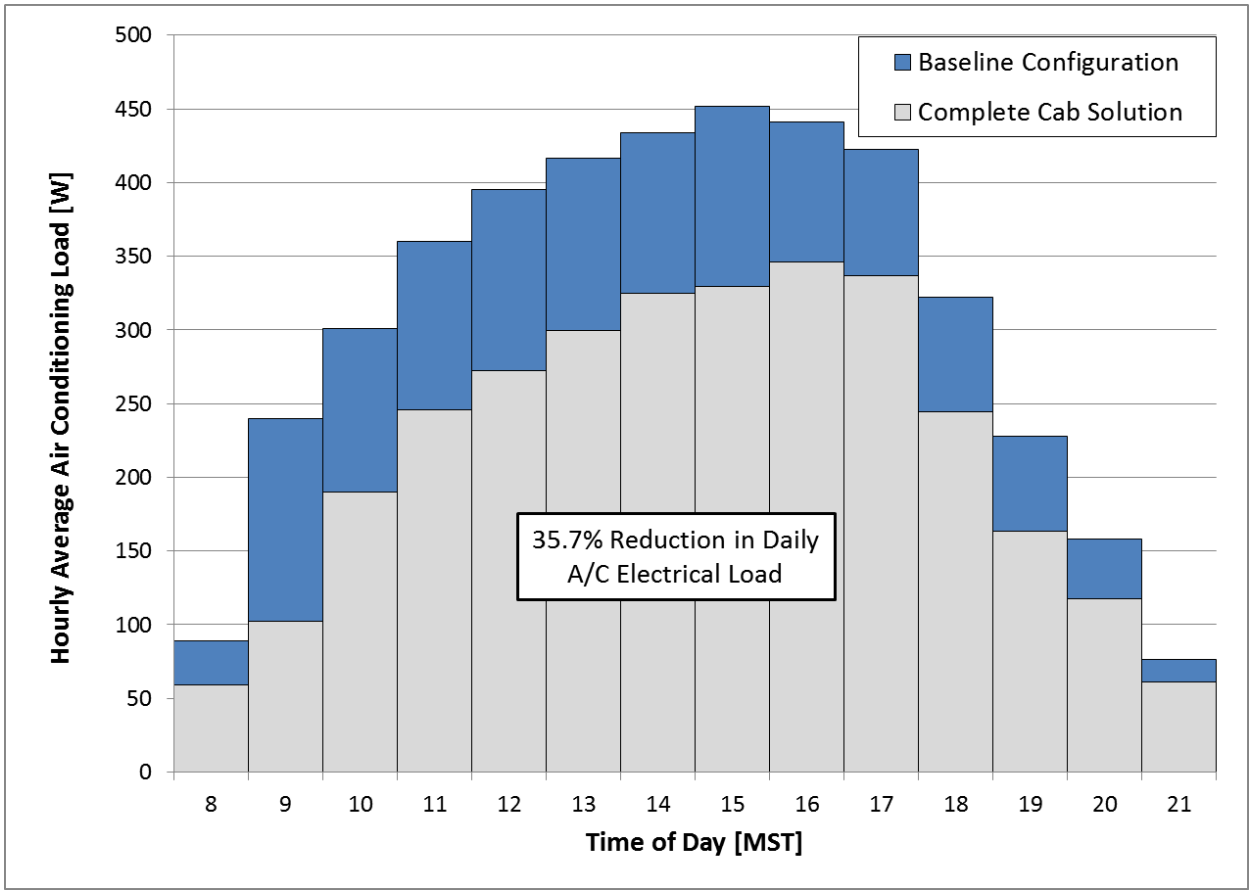


(1) Cab and (2) sleeper thermocouple locations; dimensions are A = 12", B = 6”, C = 18”; blue = TMC standard, red = NREL added.

- 40 thermocouples per vehicle
  - *Air and surface locations, following TMC-recommended practice with additional locations*
- U_{95} = ± 0.3°C
- A/C Power = ± 15 W

Prior Accomplishment: A/C Testing—Complete Cab Solution

35.7% Reduction in Daily A/C Energy with Complete Cab Solution



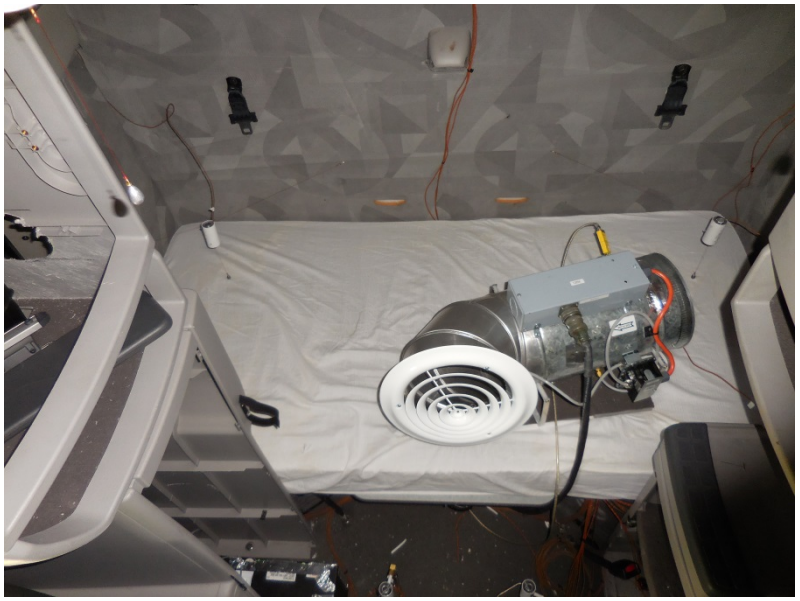
Baseline Configuration	Complete Cab Solution
	
National Average Paint	Ultra-White Paint
Stock Insulation	Advanced Insulation
Stock Sleeper Curtain	Advanced Sleeper Curtain
Stock Privacy Shades	Advanced Privacy Shades

Exceeded target of 30% reduction for cooling loads

Accomplishment: Experimental Setup – UA

Heating Load: $Q=U\cdot A\cdot \Delta T$, if $(U\cdot A)\downarrow \Rightarrow Q\downarrow$

- Forced-air heater on sleeper bed
  - Diffuser oriented to avoid air stratification
  - Power meter
- Local weather station at test site
  - Ambient air temp, wind speed, downwelling IR radiation, precipitation
- Data collection
  - 12:00am to 6:00am with 1Hz frequency, averaged over one minute



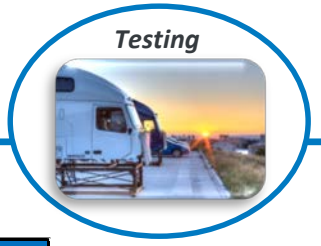
One-hour UA segments selected for steady-state conditions defined by:	
Variation in $T_{ambient}$	< 3°C
Average wind speed	< 3.58 m/s
Average net downwelling IR	< -85 W/m^2
Variation in heater power	< 15%
No precipitation	0 mm

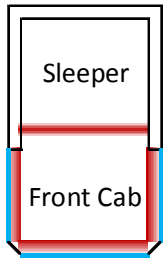
$$UA = \frac{Q_{heater}}{\bar{T}_{Sleeper} - \bar{T}_{Ambient}}$$

$$R = \frac{A}{UA}$$

UA Test Configurations & Results

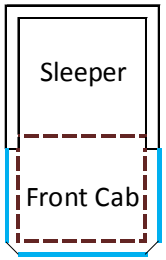
43.0% Reduction in Sleeper UA with Complete Cab Solution

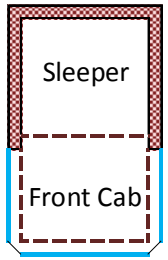




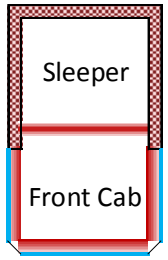
Advanced Curtains & Shades	Configuration	Reduction in UA
Insulation	Standard	20.6%
Privacy Shades	Advanced	
Sleeper Curtains	Advanced	

Control Cab





Advanced Insulation	Configuration	Reduction in UA
Insulation	Advanced	20.7%
Privacy Shades	Standard	
Sleeper Curtains	Standard	

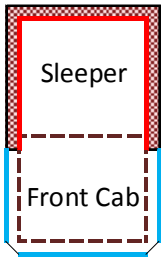


Complete Cab Solution	Configuration	Reduction in UA
Insulation	Advanced	43.0%
Privacy Shades	Advanced	
Sleeper Curtains	Advanced	

Note: Ultra-white paint on test cab is not expected to have significant impact on UA testing at night.

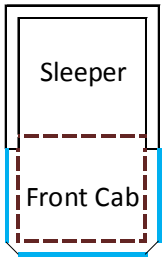
UA Test Configurations & Results - Continued

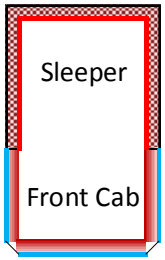
*53.0% Reduction in Sleeper UA with Complete Cab **Plus** Solution*



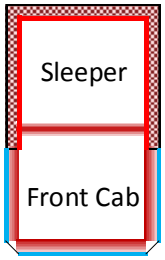
Advanced+ Insulation	Configuration	Reduction in UA
Insulation	Advanced+	33.6%
Privacy Shades	Standard	
Sleeper Curtains	Standard	

Control Cab



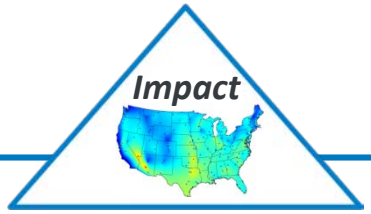


Advanced+ Insulation with Open Sleeper Curtains	Configuration	Reduction in UA
Insulation	Advanced+	21.6%
Privacy Shades	Advanced	
Sleeper Curtains	- Open -	



Complete Cab Plus Solution	Configuration	Reduction in UA
Insulation	Advanced+	53.3%
Privacy Shades	Advanced	
Sleeper Curtains	Advanced	

Note: Ultra-white paint on test cab is not expected to have significant impact on UA testing at night.



CoolCalc with high-performance computing system

Individual Tasks

Completed Tasks

CoolCalc/HPC Interface

High-performance Computing (HPC) Server and Job Manager

Node 1

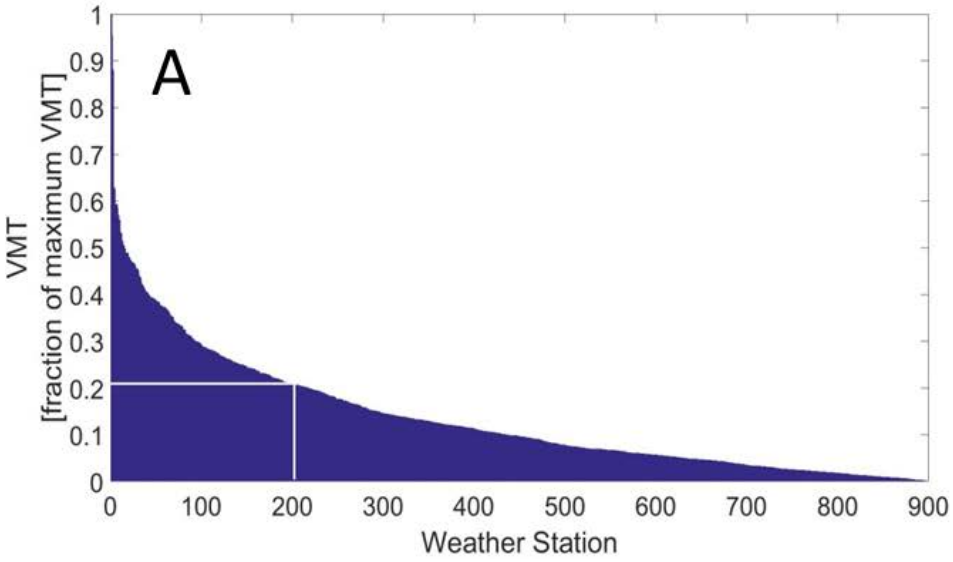
Node 2

Node i

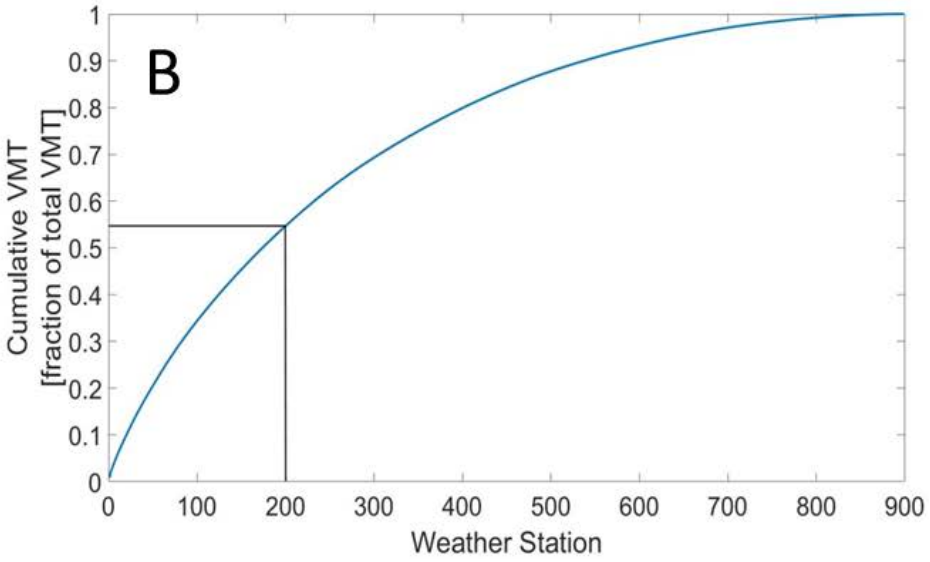
Accomplishment: Weather Locations

Calculated VMT weighting using U.S. long-haul truck traffic data*

VMT by Weather Station



Cumulative by Weather Station



*VMT = Vehicle miles traveled

Accomplishments: Weather Station Elimination

Selected 200 most representative cities by VMT, calculated weightings

Weather Stations

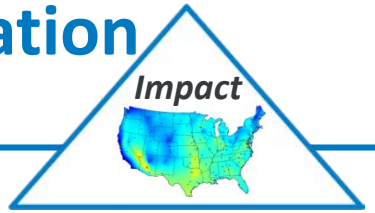
A

Top 200 VMT Miles

B

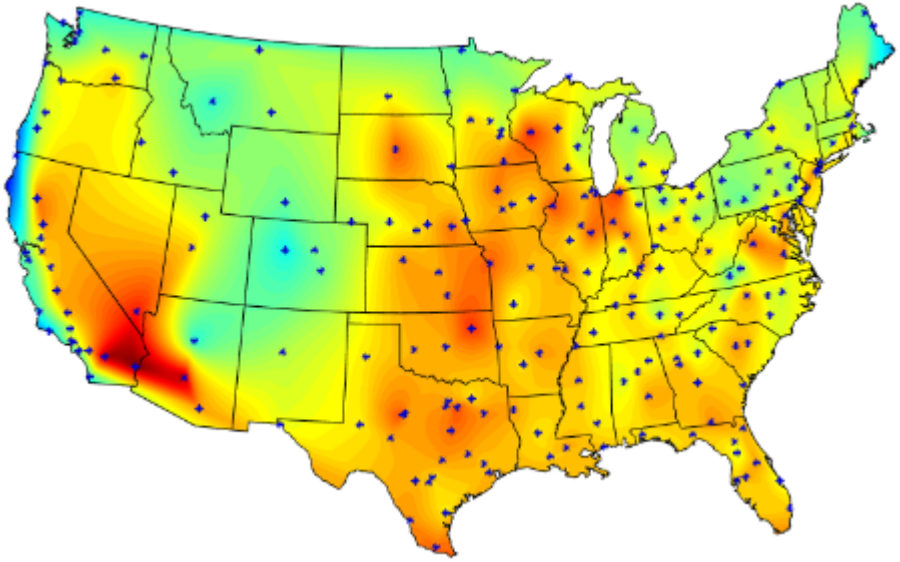
Accomplishments: Complete Cab Solution Simulation

Large national impact for Complete Cab solution on cooling loads

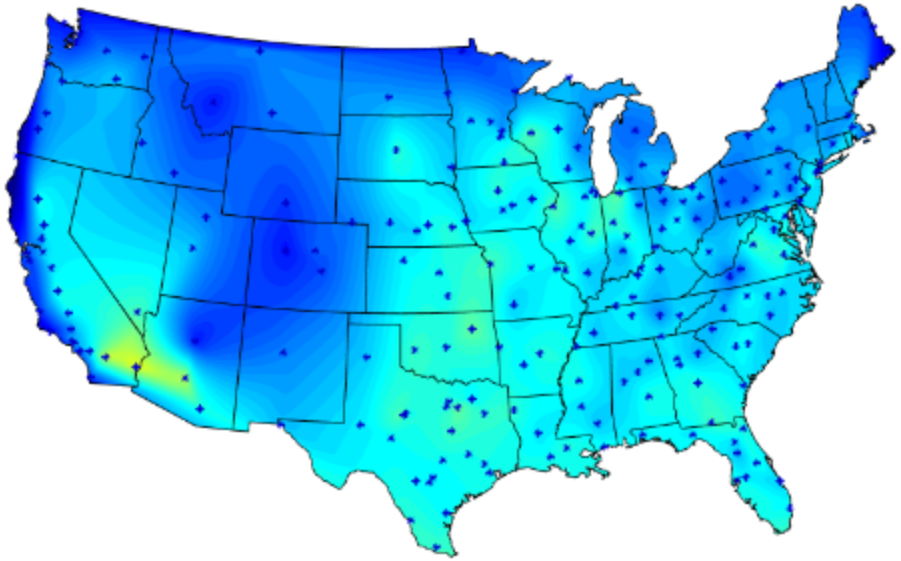


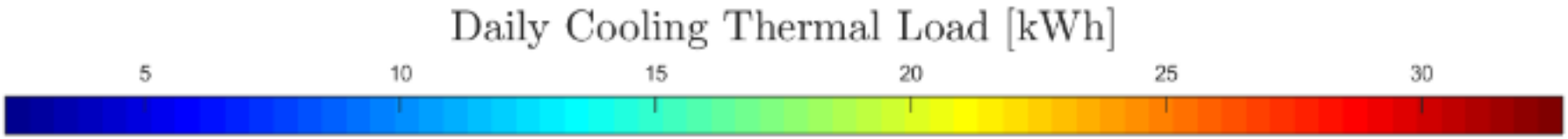
95th Percentile of Daily Cooling Loads (based on 200 Locations)

Baseline Configuration



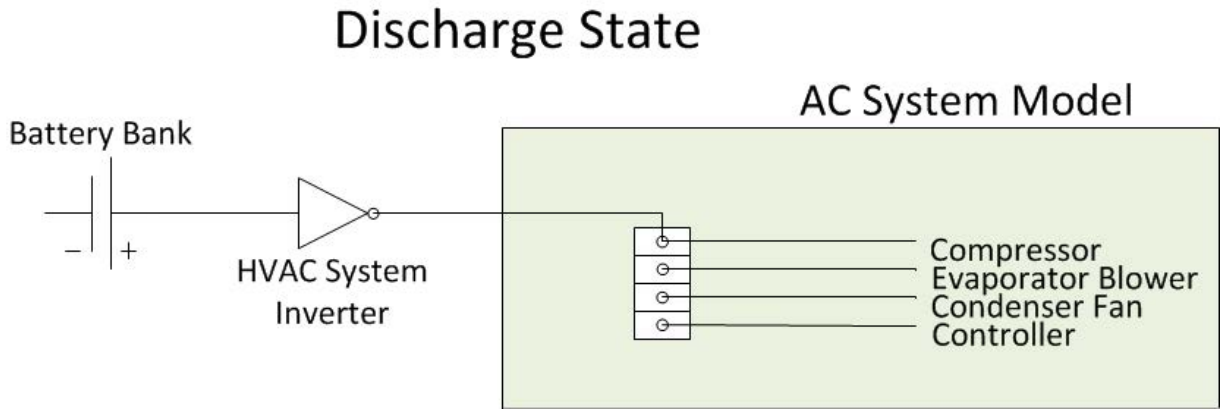
Complete Cab Solution

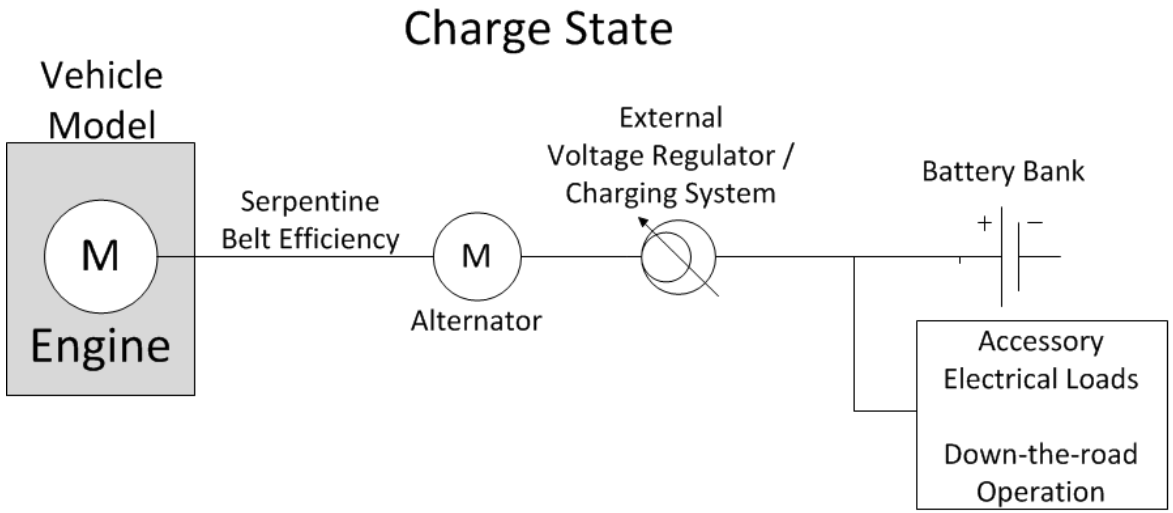




Accomplishments: A/C Systems

Modeling Auxiliary Electric Sleeper System Performance





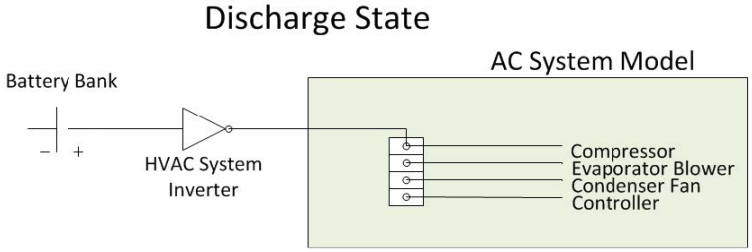
Battery and Discharge Assumptions

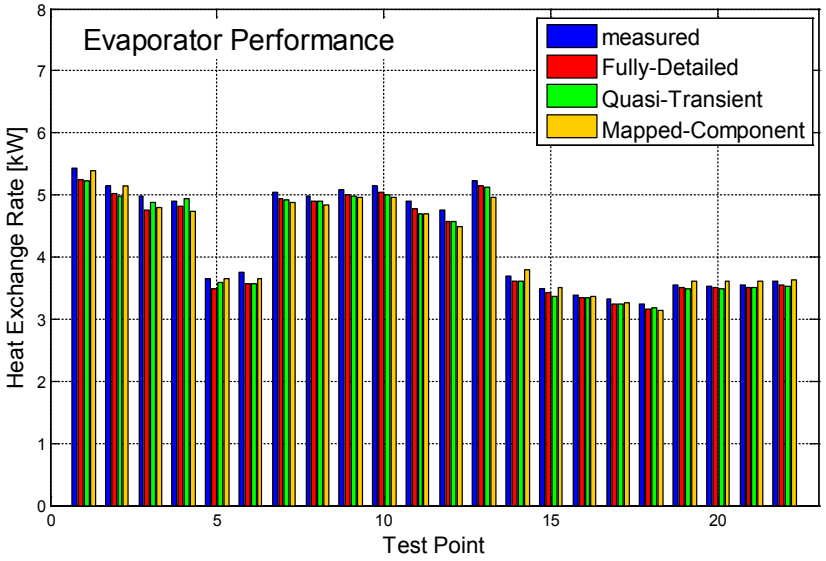
- **Standard cab is compared to a cab equipped with:**
  - Auxiliary “no-idle” electric A/C system
    - Standard configuration: pack of 8 x 104-Ah 12-V AGM 31 batteries ≈ 10 $kWh_{electric}$ capacity

- **Discharge assumptions**
  - Average annual COP

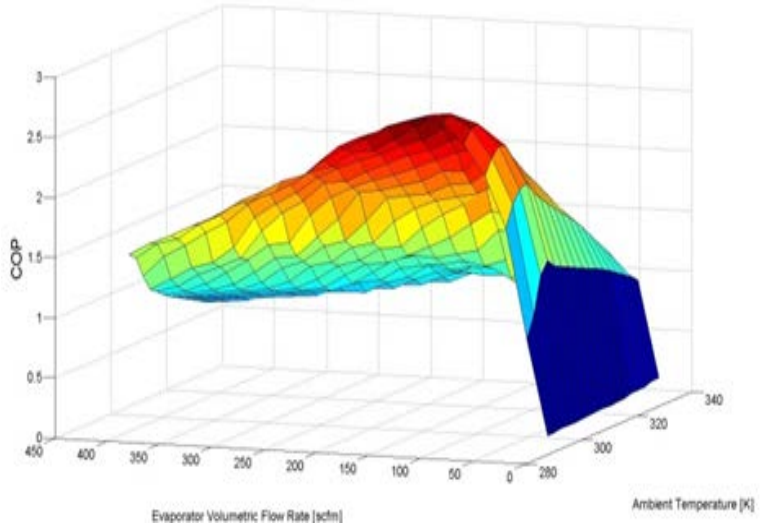
$$COPAirCond = \frac{Annual\ Cooling\ Load}{Annual\ Electric\ Power} \approx 1.83$$

  - Inverter efficiency 90%





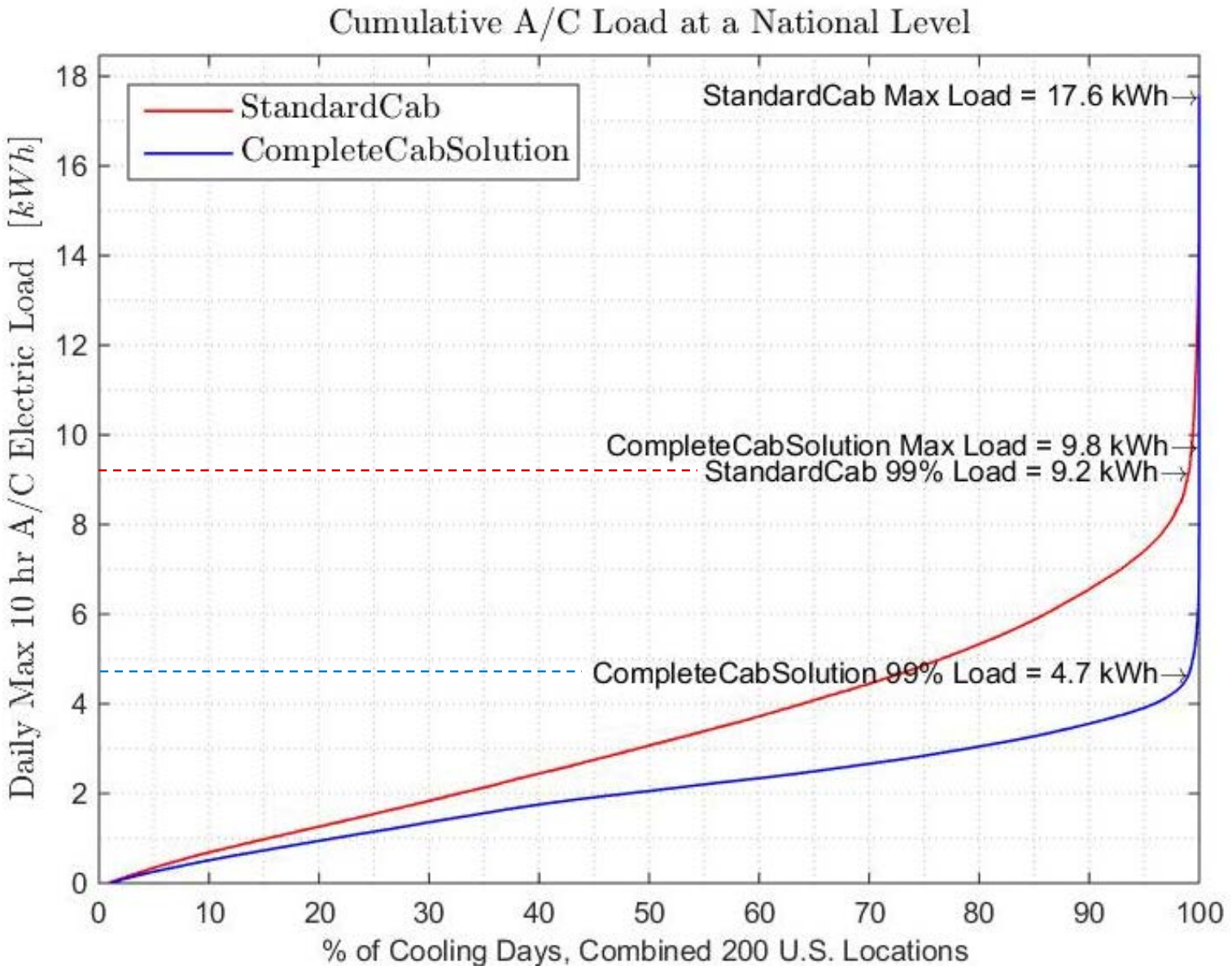
Generic idle-off system model response



COP = coefficient of performance

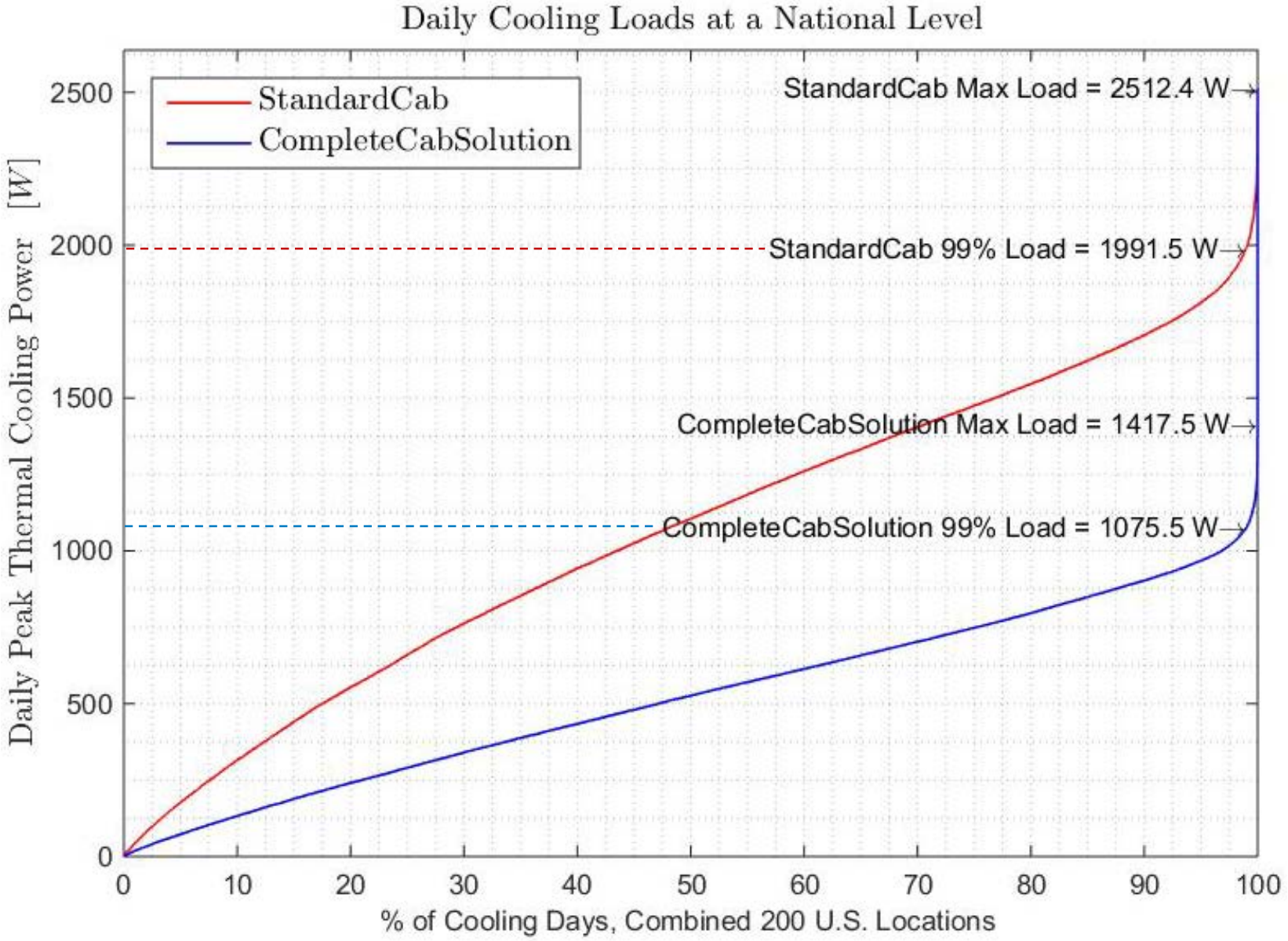
Accomplishments: A/C System Sizing

Battery capacity sizing



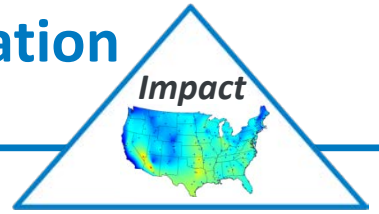
Accomplishments: A/C System Sizing

Peak (thermal) power benefits



Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm



Daily Discharge Statistics

June 8
Final SOC = 0.31
June 9
Final SOC = 0.00
Final SOC = 0.76
June 10
Final SOC = 0.40
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Final SOC = 0.09
June 12
Final SOC = 0.27
June 13
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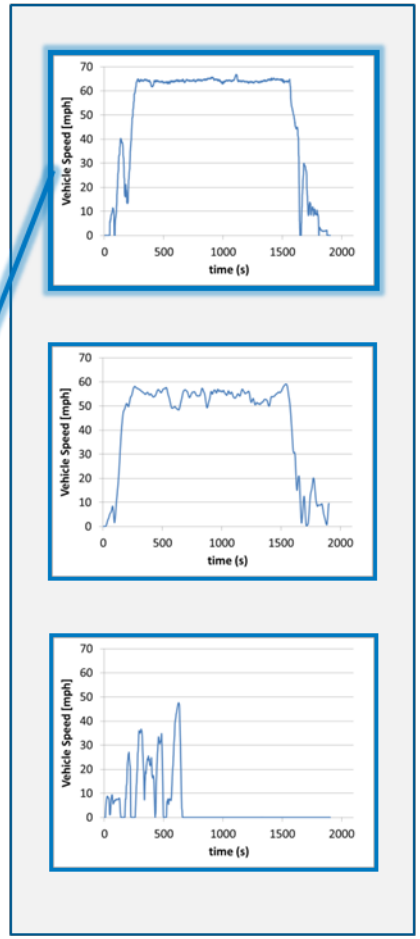
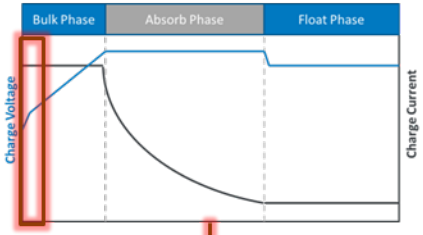
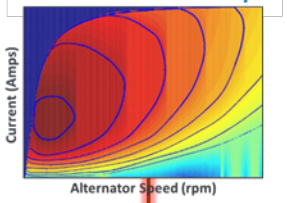


Battery Charging Algorithm



$i_{battery} + i_{other}$

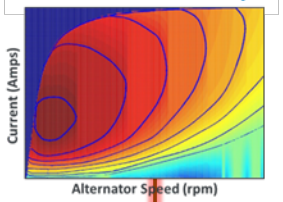
Alternator Map



Fuel Use Without Battery Charging

i_{other}

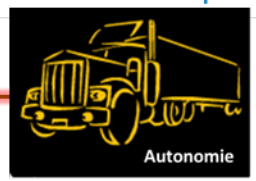
Alternator Map



$$P_{accessory} = i_{tot} * V_{bus} * \eta_{regulator} * \eta_{alternator} * \eta_{belt}$$

Vehicle Map

Vehicle Map

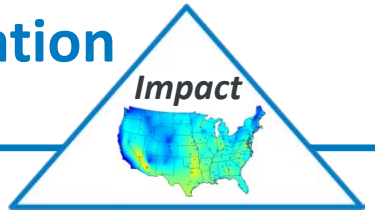


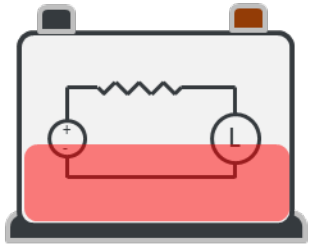
Battery Recharge Fuel Use

**State of charge (SOC)*

Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm

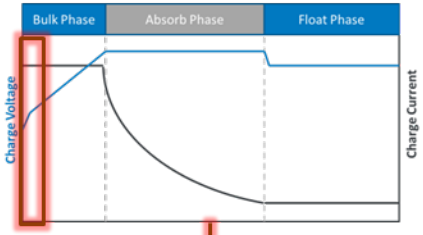




Update Battery SOC

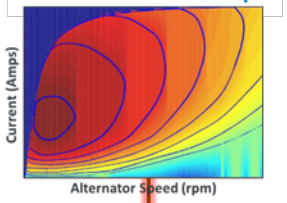
**State of charge (SOC)*

Battery Charging Algorithm



$i_{battery} + i_{other}$

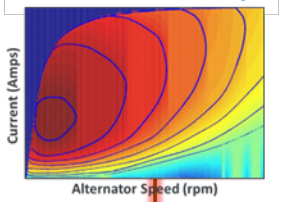
Alternator Map



Fuel Use Without Battery Charging

i_{other}

Alternator Map



$$P_{accessory} = i_{tot} * V_{bus} * \eta_{regulator} * \eta_{alternator} * \eta_{belt}$$

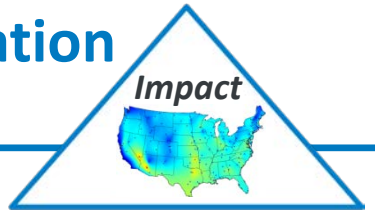
Vehicle Map

Vehicle Map

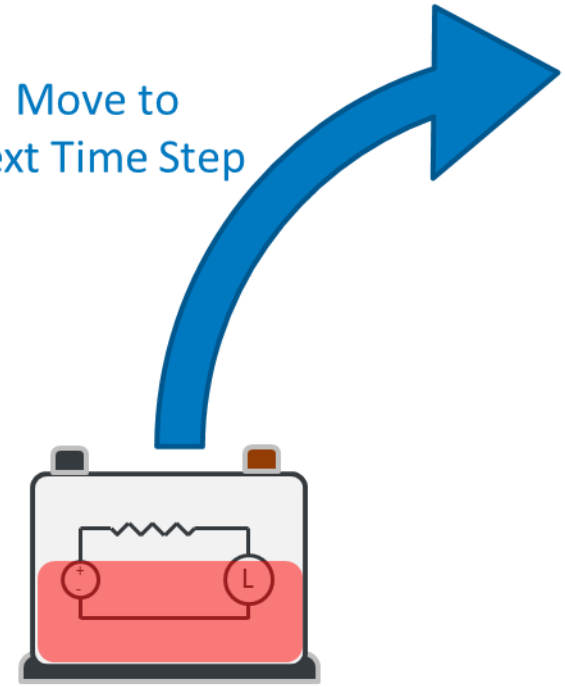
Battery Recharge Fuel Use

Accomplishments: CoolCalc Modeling—Fuel Use Estimation

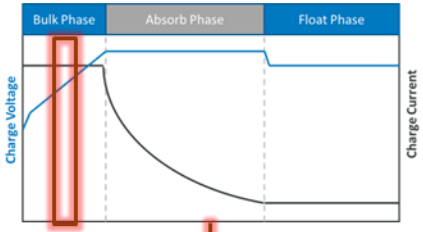
Battery Recharge Algorithm



Move to Next Time Step

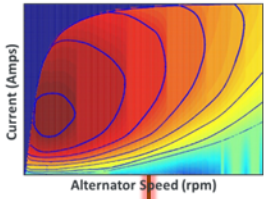


Battery Charging Algorithm



$i_{battery} + i_{other}$

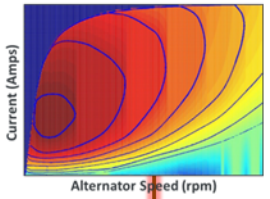
Alternator Map



Fuel Use Without Battery Charging

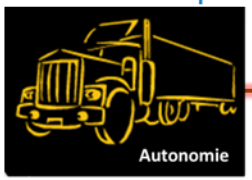
i_{other}

Alternator Map

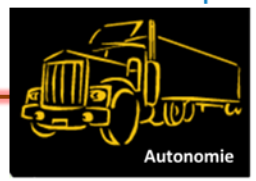


$$P_{accessory} = i_{tot} * V_{bus} * \eta_{regulator} * \eta_{alternator} * \eta_{belt}$$

Vehicle Map



Vehicle Map

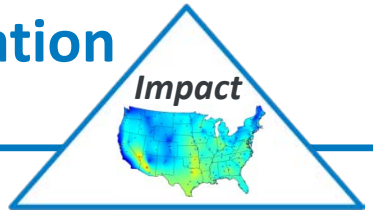


Battery Recharge Fuel Use

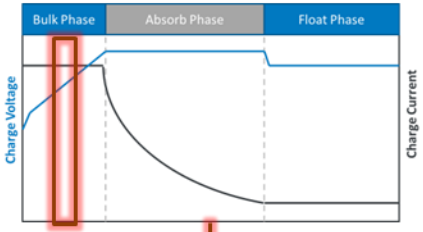
**State of charge (SOC)*

Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm



Battery Charging Algorithm

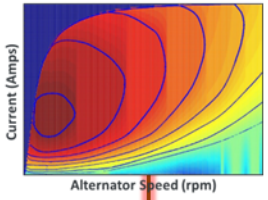


$i_{battery} + i_{other}$

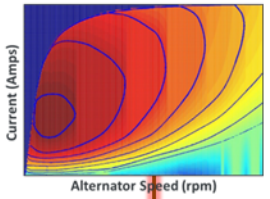
Fuel Use Without Battery Charging

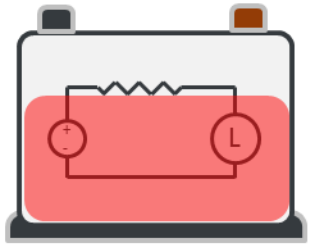
i_{other}

Alternator Map



Alternator Map

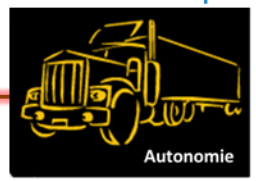




$$P_{accessory} = i_{tot} * V_{bus} * \eta_{regulator} * \eta_{alternator} * \eta_{belt}$$

Vehicle Map

Vehicle Map



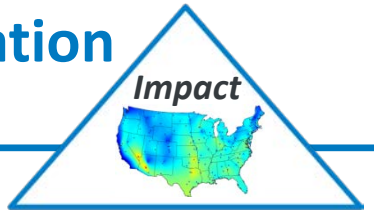
Update Battery SOC

Battery Recharge Fuel Use

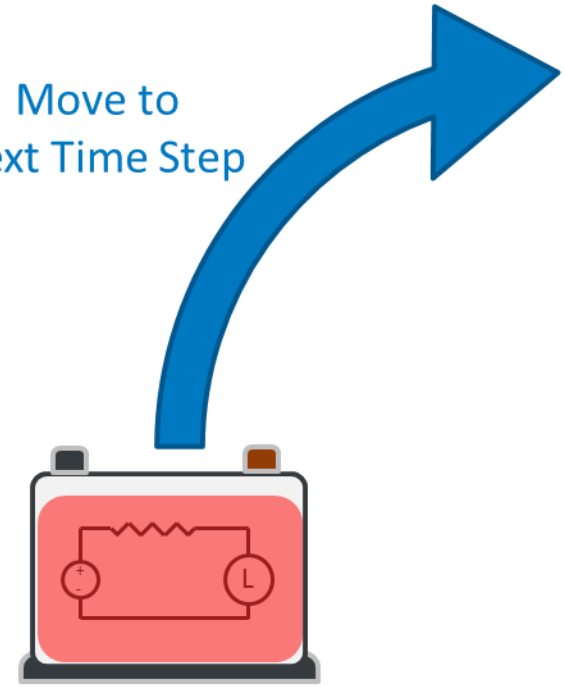
**State of charge (SOC)*

Accomplishments: CoolCalc Modeling—Fuel Use Estimation

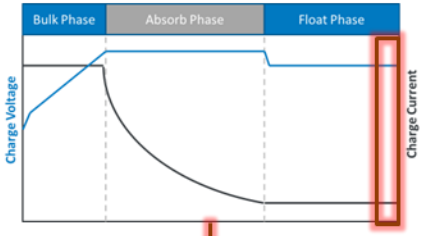
Battery Recharge Algorithm



Move to
Next Time Step

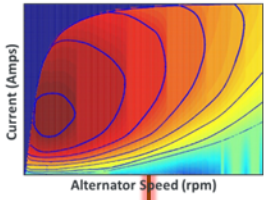


Battery Charging Algorithm



$i_{battery} + i_{other}$

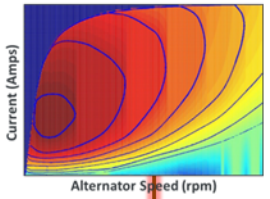
Alternator Map



Fuel Use Without Battery Charging

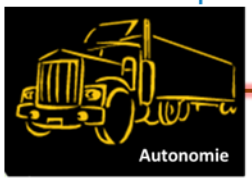
i_{other}

Alternator Map

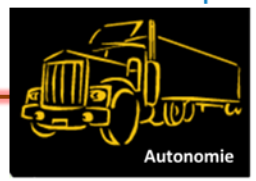


$$P_{accessory} = i_{tot} * V_{bus} * \eta_{regulator} * \eta_{alternator} * \eta_{belt}$$

Vehicle Map



Vehicle Map

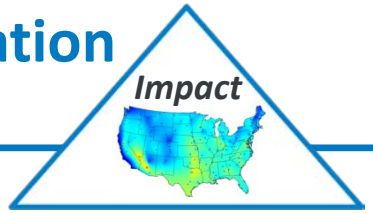


Battery Recharge Fuel Use

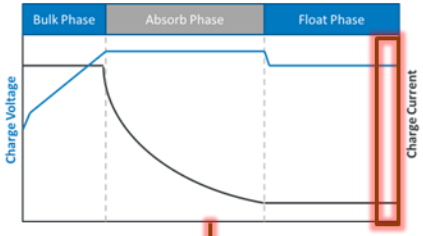
**State of charge (SOC)*

Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm



Battery Charging Algorithm

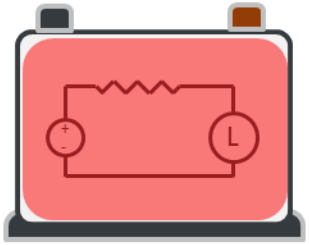


$i_{battery} + i_{other}$

Fuel Use Without Battery Charging

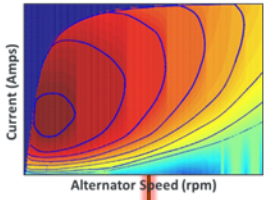
i_{other}

Battery Fully Recharged

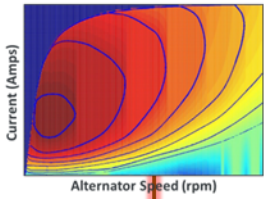


Update Battery SOC

Alternator Map

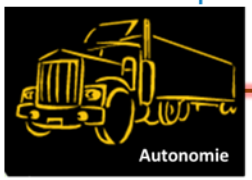


Alternator Map

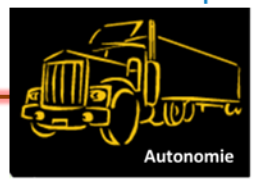


$$P_{accessory} = i_{tot} * V_{bus} * \eta_{regulator} * \eta_{alternator} * \eta_{belt}$$

Vehicle Map



Vehicle Map

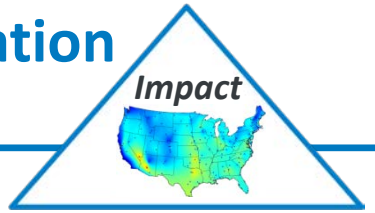


Battery Recharge Fuel Use

**State of charge (SOC)*

Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm



Daily Discharge Statistics

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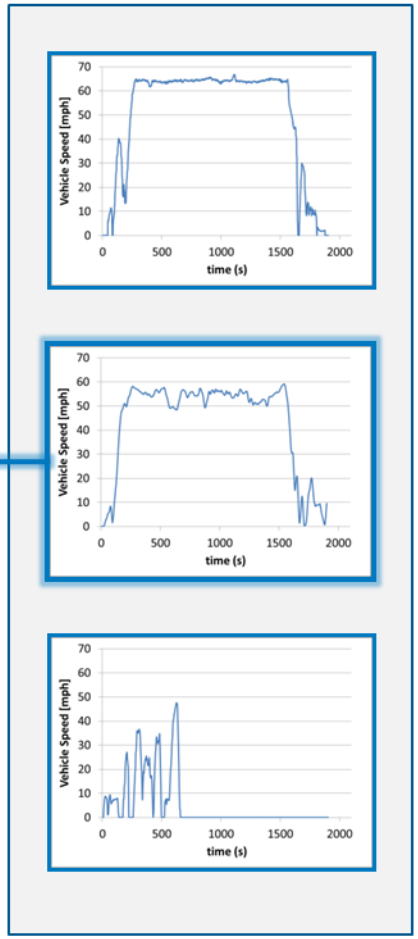
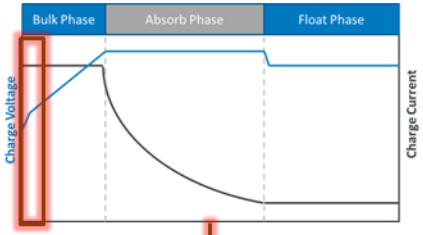


Battery Charging Algorithm

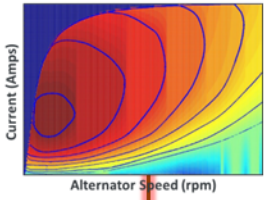


$i_{battery} + i_{other}$

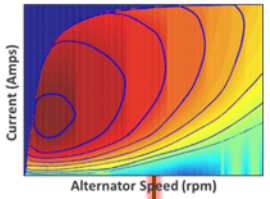
Fuel Use Without Battery Charging

i_{other}

Alternator Map



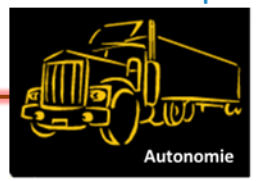
Alternator Map



$$P_{accessory} = i_{tot} * V_{bus} * \eta_{regulator} * \eta_{alternator} * \eta_{belt}$$

Vehicle Map

Vehicle Map

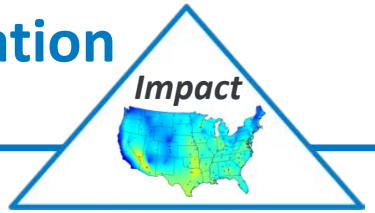


Battery Recharge Fuel Use

**State of charge (SOC)*

Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm



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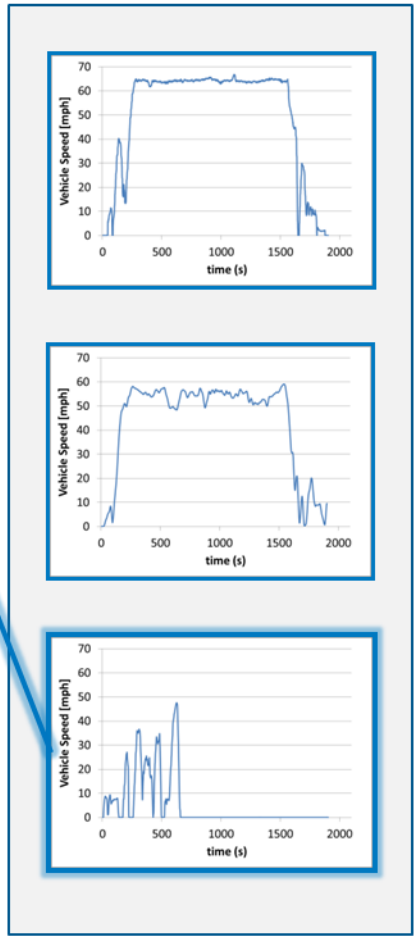
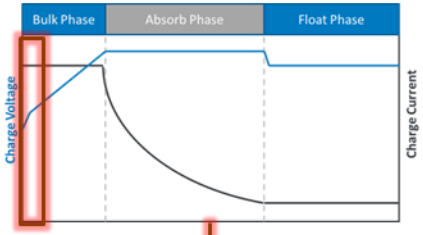


Battery Charging Algorithm

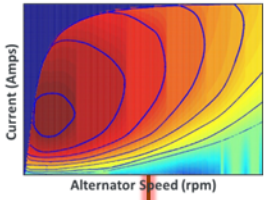


$i_{battery} + i_{other}$

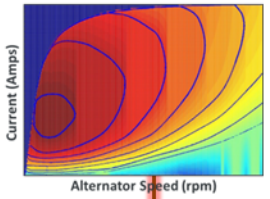
Fuel Use Without Battery Charging

i_{other}

Alternator Map



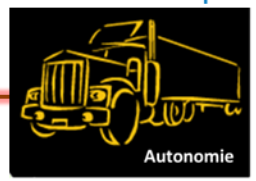
Alternator Map



$$P_{accessory} = i_{tot} * V_{bus} * \eta_{regulator} * \eta_{alternator} * \eta_{belt}$$

Vehicle Map

Vehicle Map

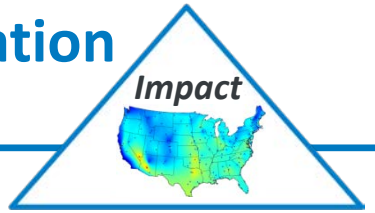


Battery Recharge Fuel Use

**State of charge (SOC)*

Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm



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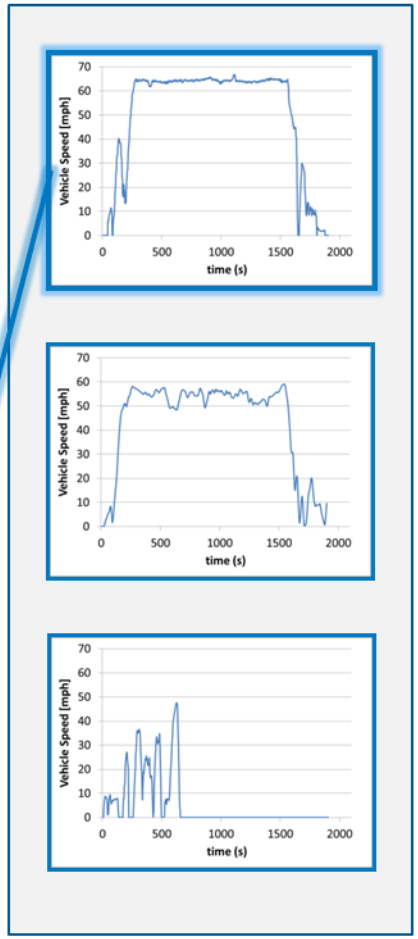
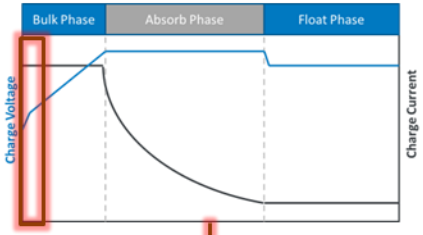
June 11
Final SOC = 0.09
June 12
Final SOC = 0.27
June 13
Final SOC = 0.67



Battery Charging Algorithm

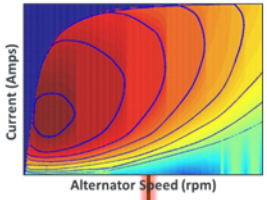


$i_{battery} + i_{other}$

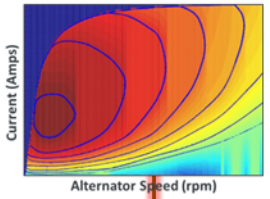
Fuel Use Without Battery Charging

i_{other}

Alternator Map



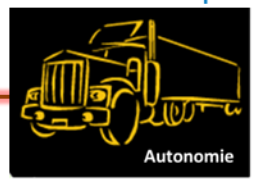
Alternator Map



$$P_{accessory} = i_{tot} * V_{bus} * \eta_{regulator} * \eta_{alternator} * \eta_{belt}$$

Vehicle Map

Vehicle Map

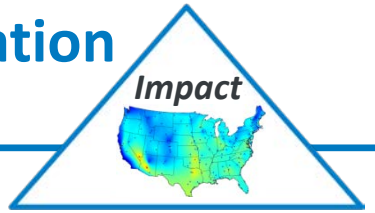


Battery Recharge Fuel Use

**State of charge (SOC)*

Accomplishments: CoolCalc Modeling—Fuel Use Estimation

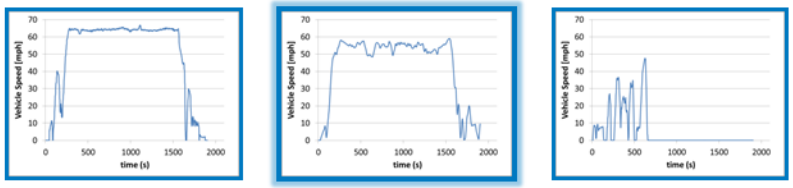
Battery Recharge Algorithm



Step 1. Determine the battery depletion for that Day

June 10
Final SOC = 0.40

Step 2. Select a Drive Cycle



Step 3: Calculate fuel use at each timestep

- Step 3a: Determine charge current
- Step 3b: Determine alternator efficiency
- Step 3c: Calculate accessory power
- Step 3d: Calculate vehicle fuel use
- Step 3e: Add incremental fuel use

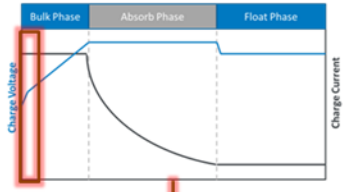
Step 4: Perform Step 3 at new timestep

Step 5: Repeat process for remaining drive cycles

**State of charge (SOC)*

Step 3.

Step 3a. Battery Charging Algorithm

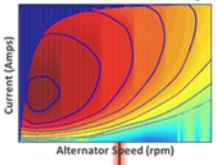


$i_{battery} + i_{other}$

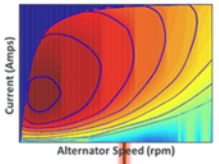
Fuel Use Without Battery Charging

i_{other}

Alternator Map



Alternator Map

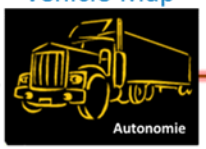


Step 3b.

Step 3c.

$$P_{accessory} = i_{tot} * V_{bus} * \eta_{regulator} * \eta_{alternator} * \eta_{belt}$$

Vehicle Map



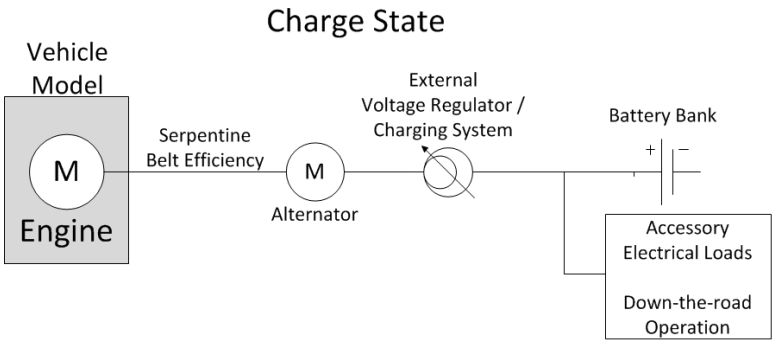
Vehicle Map

Step 3d.

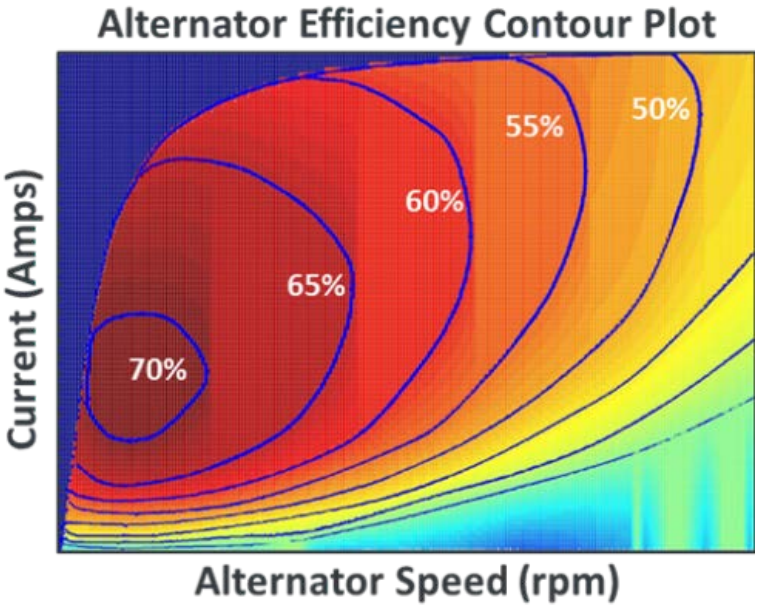
Step 3e. Battery Recharge Fuel Use

Step 4.

Charging Assumptions



- Serpentine Belt Efficiency: 98%
- Charging Voltage Regulator Efficiency: 85%*

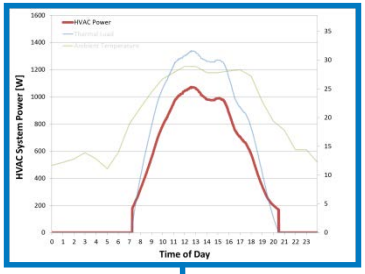


- Vehicle model
  - Non-proprietary open-use Class 8 long-haul truck vehicle model developed by Oak Ridge National Laboratory
  - The vehicle model was modified to match the EPA GEM Model Class 8 combination tractor modeling parameters

* HDM Systems Corp: http://www.hdm-sys.com/pdf/HDM-PB-VISTER-12V-HIC-Series-20120608-1035.pdf

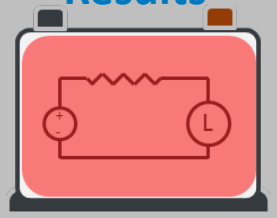
Accomplishments: Fuel Use Estimation

HVAC Load Profile

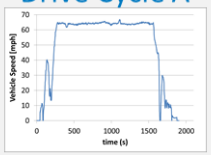


HVAC Energy

Recharge Results

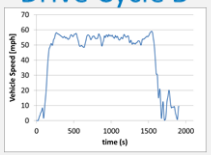


Drive Cycle A



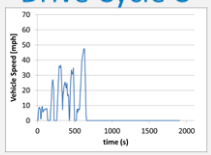
Fuel Use

Drive Cycle B



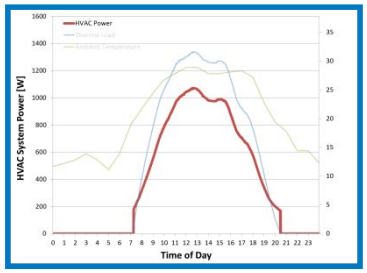
Fuel Use

Drive Cycle C



Fuel Use

Cycle Weighting Fractions: **86%** **9%** **5%**



HVAC Energy

Fuel Use

Modeling: Idling Assumptions

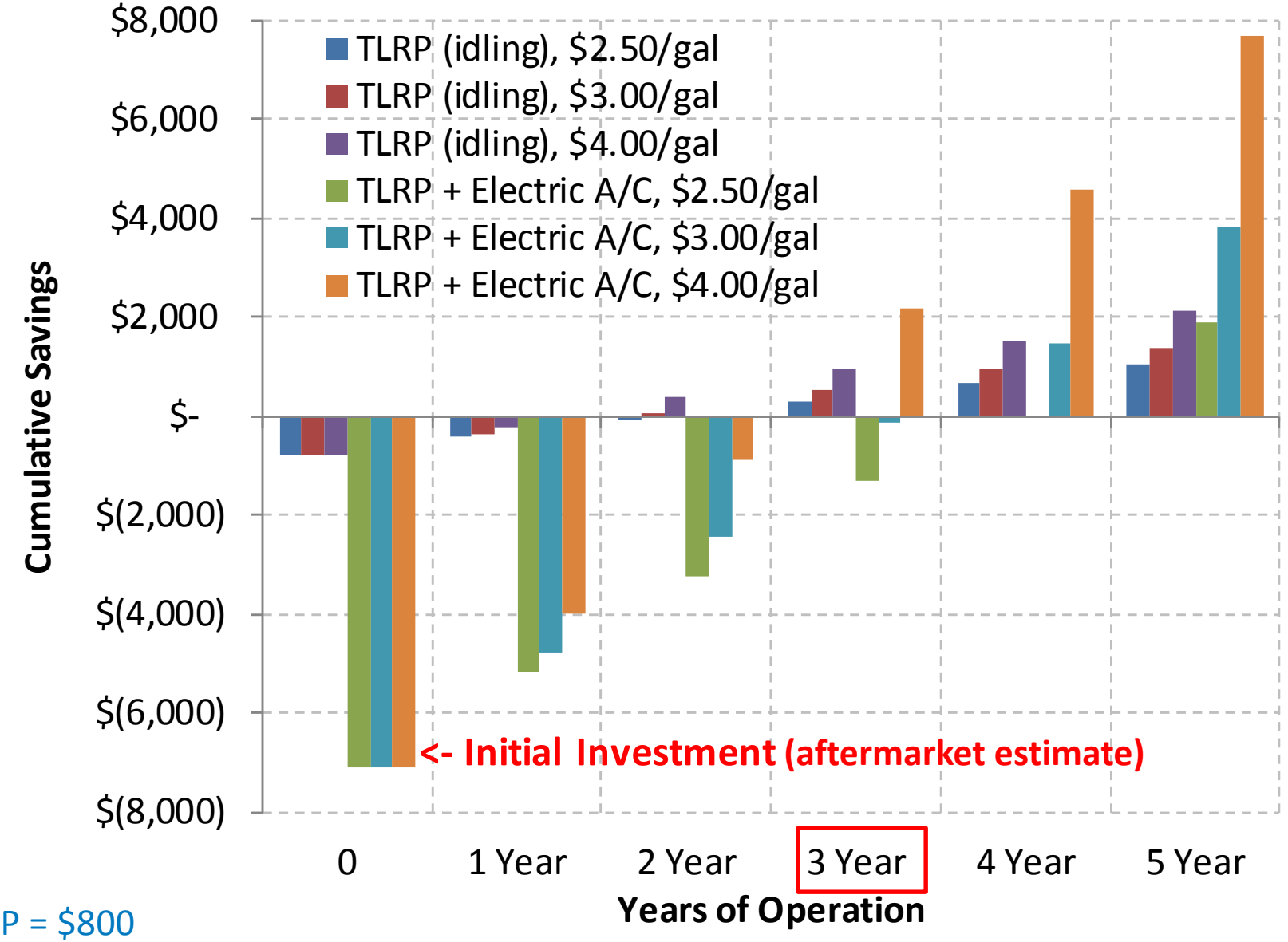
- **Idling fuel consumption rate: 0.8 gal/h***
- **Rest period duration: 10 h/day**
- **Number of rest periods per year: 260**

  52 weeks/year x 5 days/week = 260 working days per year

  on conservative side compared to prior estimate of 250–300 days*

* Lim, H. "Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices." U.S. Environmental Protection Agency. EPA420-R-02-025, October 2002.

Accomplishment: Battery electric idle-off with thermal load reduction package (TRLP), A/C Only, *774 gallons saved, 3-year payback at $3/gallon*



TLRP = $800

Accomplishments: A/C System Sizing Benefits

- **Meeting 5.2 $kWh_{electric}$ load with 4 batteries (instead of 8)**
- **Savings of $700 during initial installation**
- **Savings up to $1,400 during 3-year operation**

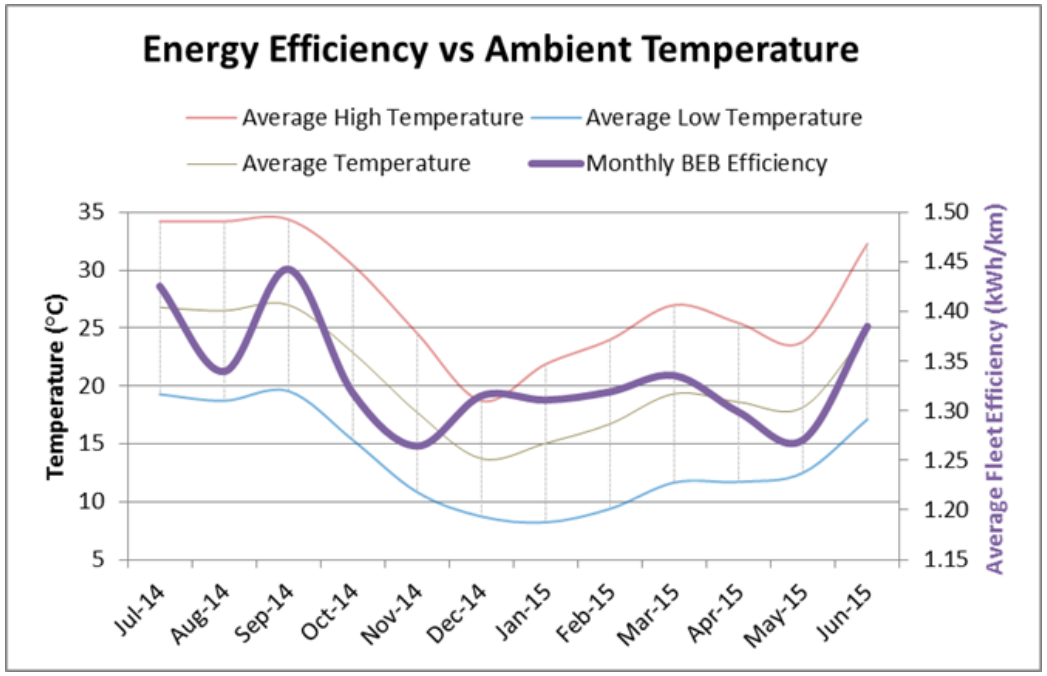
  (assuming one battery replacement during 3-year period)

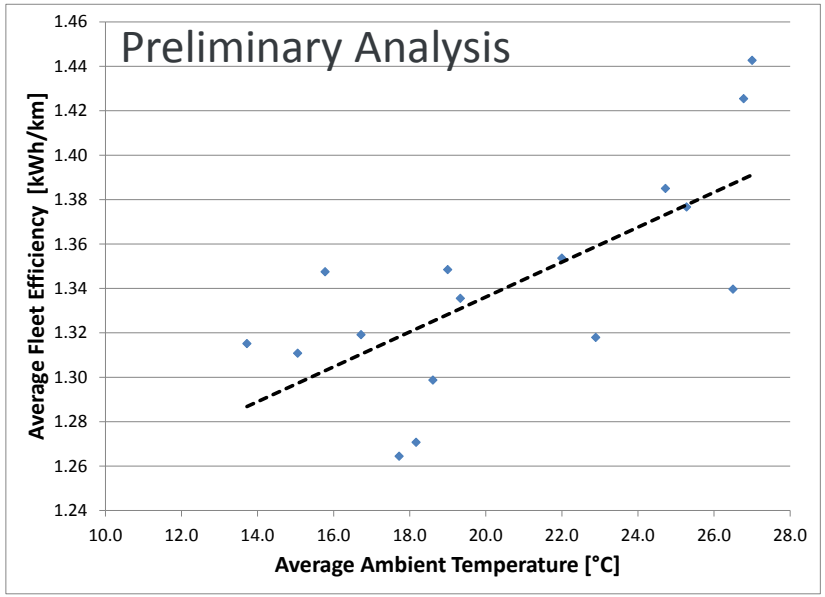
"No-Idle" Electric A/C System Configuration	Number of 104 Ah (1248 Whr @ 12V) Batteries	Cost per Battery	Initial Cost Reduction of Electric A/C System	Number of Replacements During 3-year Period	Battery Replacement Cost During 3-year Period	Savings During 3-year Period
Standard electric A/C system	8	$ 175	$ -	1	$ 1,400	$ -
Electric A/C system with reduced battery pack	4		$ 700	1	$ 700	$ 1,400

Accomplishments: Other Commercial Vehicle Applications

Preliminary Electric Bus Analysis

- Initial analysis of electric bus data collaborating with Fleet Test and Evaluation team
- Further details need investigation, but clear impact of ambient temperature
- Investigating opportunities to improve performance of electric buses to help their adoption and increase fuel displacement





Collaboration

- 21st Century Truck Partnership
- Kenworth
  - Fully instrumented and tested for thermal-load measurements
  - Developed, validated, and released CoolCalc model
- Volvo Trucks
  - Completed thermal testing
  - Developed and validated CoolCalc model,
  - CoolCalc model application in progress
- Daimler Truck, Super Truck Program
  - Completed thermal testing of Super Truck
  - Developed and validated CoolCalc model
- PPG Industries
  - Evaluated advanced paint technology
- Aearo Technologies LLC
  - Evaluated insulation packages
- Measurement Technology Northwest
  - Thermal manikin testing
- In discussion with several commercial vehicle partners for other vocations

Responses to FY15 AMR Reviewer Comments (for previous phase of project)

Comment:	The reviewer stated that the approach appears to address all the sources of heat that influence the temperature in a sleeper cab. The model development will be a useful tool in future sleeper cab design activities. The reviewer would be interested to see if this approach could be applied to day cabs as well.
Response:	We agree with the reviewer. We are working toward applying the tools to sleeper cab design and toward other commercial vehicle applications such as day cabs. The focus of the next phase of the project, which started this year, is to expand to commercial vehicle applications.

Comment:	The reviewer commented that the proposed future research is a logical progression that increases the value of this project's products.
Response:	Thank you for the feedback. We are working toward applying these tools to the broader commercial vehicle market. We will strive to add continued value to the long-haul truck market while helping identify and develop thermal load reduction technologies for other applications such as day cabs, buses, shuttle vans, worksite trucks, and other applications.

Comment:	The reviewer stated that the project is well designed. The milestones are distinct and easy to understand. The project progression is very orderly. The reviewer added that the mirror image between the technology development and the analytical tool development is an important breakthrough. Too many tech development projects either develop the analytical tool after the technology development or do not develop one at all.
Response:	We plan to carry this mirror image technology development and analytical tool development forward in this next phase of the project. Adapting these tools to other vehicle applications will provide new opportunities to increase vehicle efficiency while continuing to improve the tools and their value to industry.

Proposed Future Work and Remaining Challenges and Barriers

- Complete heating load analysis for long-haul trucks
- Commercial vehicle applications (day cab, buses, shuttle vans, other applications)
- Build partnerships from initial discussions with commercial vehicle companies
- Transition approach, tools, and methods to broader commercial vehicle focus
- Identify most promising opportunities and develop solutions in collaboration with industry

Summary / Conclusions

Exceeded 30% HVAC load reduction goal and met 3-year payback

Experimental Outdoor Testing

- Collaborated with industry partners to experimentally evaluate long-haul truck rest period idle-load reduction technologies

Complete Cab Test Configuration	A/C Reduction	UA heating reduction	UA Heating Reduction Advanced Plus
Insulation, Adv. Curtains, and Adv. Shades	35.7%	43.0%	53.3%
Insulation, Stock curtains, Stock Shades	21.1%	20.7%	33.6%
Insulation, No curtains, Adv. Shades	11.6%	--	21.6%

CoolCalc Modeling

- National-level analysis of battery electric system with thermal load reduction: 774 gallons saved, 3-year payback at $3/gallon (considering cab heating will further improve payback)
- Capabilities for engineering design (battery sizing)

Contacts

Special thanks to:

- **David Anderson and Lee Slezak** ***Vehicle Systems technology managers, DOE***

For more information:

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303-275-4443

Photo Credits

- **Slide 1**
  1. Photograph of NREL's Vehicle Test Pad (VTP), Dennis Schroeder, NREL
- **Slide 4 NREL Image Gallery**
  1. 142 Pierce Transit
  2. 229, Dennis Schroeder
  3. 304, Dennis Schroeder
  4. 95, Raley's
- **Slide 8**
  1. Thermal image of truck, Dennis Schroeder, NREL
  2. AC system, Cory Kreutzer
- **Slide 9**
  1. Photos of trucks on VTP, Cory Kreutzer, NREL
- **Slide 13**
  1. Dennis Schroeder, NREL
- **Slide 14**
  1. Cory Kreutzer, NREL
- **Slide 15**
  1. Bidzina Kekelia, NREL
- **Slide 32**
  1. Leslie Eudy, NREL
- **Slide 33**
  1. Photograph of Daimler truck, Travis Venson,
  2. Photograph of Volvo truck, Cory Kreutzer, NREL
  3. Photograph of Kenworth truck, Ken Proc, NREL
  4. Photograph of Vehicle Test Pad, Dennis Scrhoeder, NREL
- **Slide 37**
  1. Photograph of trucks on VTP, Cory Kreutzer, NREL

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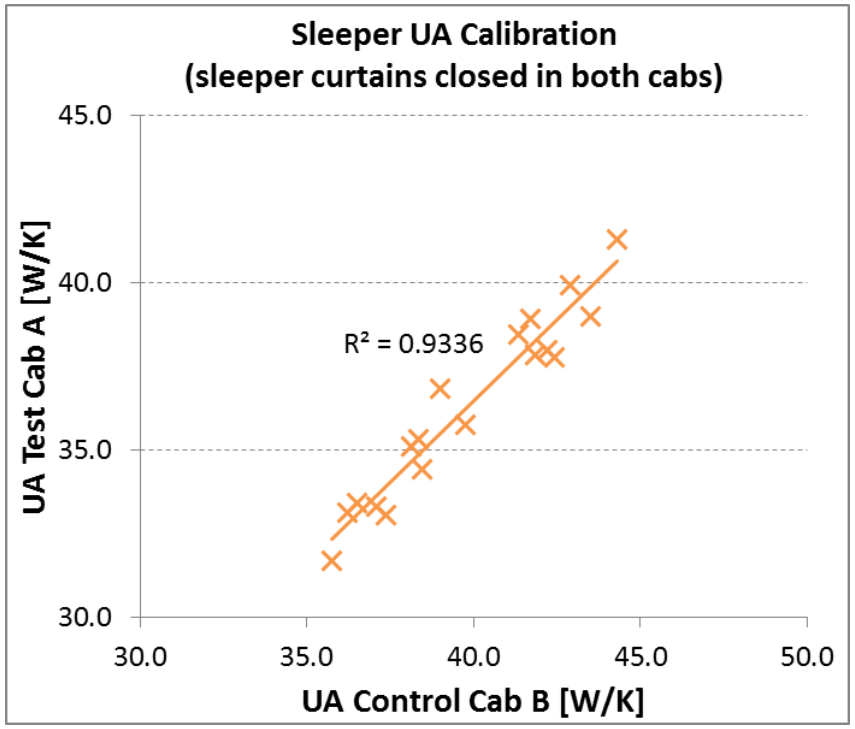
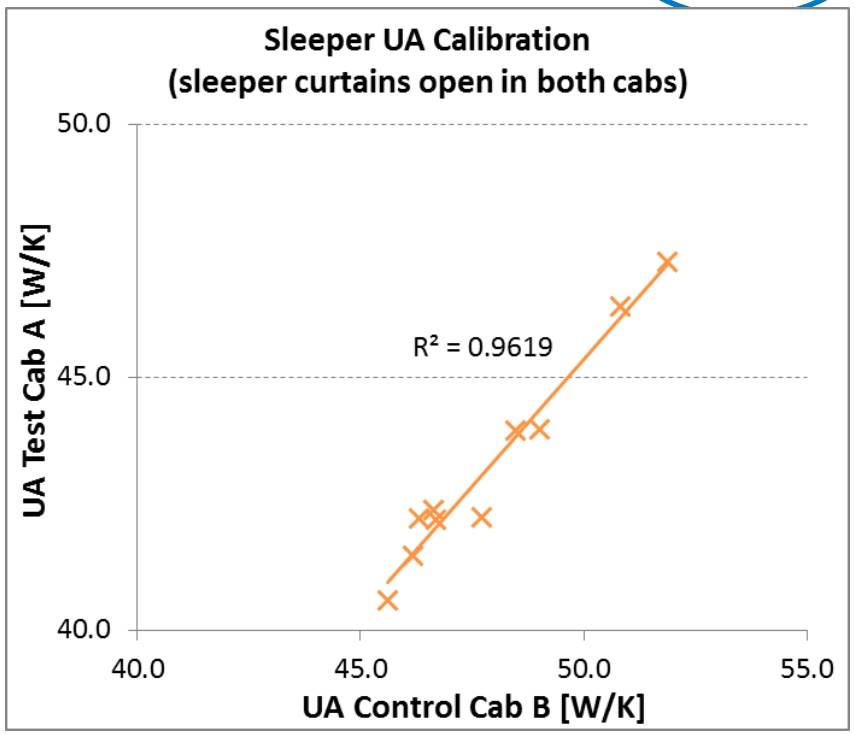
Technical Backup

Accomplishment :Experimental Heater Testing – UA

Overall Heat Transfer Coefficient (UA) testing





Baseline Configuration I

- Stock curtains and shades
- Baseline insulation

Baseline Configuration II

- Stock privacy shades only
- Baseline insulation

Note: Ultra-White paint for both (not expected to have significant impact on UA testing at night)