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

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Project ID #VS075

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

Timeline

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

Budget

Total Project Funding: (Commercial Vehicle Thermal Load Reduction /VTCab):
- Funding for FY16: $250K/$175K

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.

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\(^2\)

### 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

<table>
<thead>
<tr>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
</table>

**M1** Screen commercial vehicle applications and build partnerships for promising applications

#### FY 2017

<table>
<thead>
<tr>
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<th>Q3</th>
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**M2** HVAC load reduction, complete next steps for long-haul trucks

<table>
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</tr>
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</table>

**M3** Test promising commercial vehicle applications, build models

#### FY 2018

<table>
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<th>Q4</th>
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<table>
<thead>
<tr>
<th>M1</th>
<th>M2</th>
<th>M3</th>
</tr>
</thead>
</table>

**M2** Perform national-level fuel use estimation and payback period analysis

**M3** Demonstrate load reduction and provide payback period estimation

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**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

<table>
<thead>
<tr>
<th>FY 2015</th>
<th>FY 2016</th>
<th>FY 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
</tbody>
</table>

**M1**  
- Fuel Use and Payback Period Tool Development
- Implement Basic VTCab GUI in Independent Platform

**M2**  
- Fuel Use-Driven Design for Commercial and Light-Duty Vehicles
- Complete VTCab GUI and Modify for New Solver

**M3**  
- Develop Cabin Thermal Model Solver In MATLAB/Simulink

**M4**  
- Integrate and Validate with CoolSim

**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

Solar Envelope

Occupant Environment

Conductive Pathways

Efficient Equipment

Relevance  Approach  Accomplishments  Collaborations  Future Work
Approach – Overall Strategy

Impact

Solar Envelope

Occupant Environment

Conductive Pathways

Efficient Equipment

Testing

Industry Collaboration

Modeling

Relevance

Approach

Accomplishments

Collaborations

Future Work
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

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Complete-Cab Package</th>
<th>Complete-Cab Plus Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paint</td>
<td>National Average Solar-Color</td>
<td>Ultra-White</td>
<td>Ultra-White</td>
</tr>
<tr>
<td>Curtains</td>
<td>Stock OEM</td>
<td>Advanced</td>
<td>Advanced</td>
</tr>
<tr>
<td>Insulation</td>
<td>Stock OEM</td>
<td>Advanced Package</td>
<td>Advanced Plus</td>
</tr>
</tbody>
</table>

- 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)

- 40 thermocouples per vehicle
  - Air and surface locations, following TMC-recommended practice with additional locations

- $U_{95} = \pm 0.3°C$
- A/C Power = ± 15 W

(1) Cab and (2) sleeper thermocouple locations; dimensions are $A = 12"$, $B = 6"$, $C = 18"$; blue = TMC standard, red = NREL added.
Prior Accomplishment: A/C Testing—Complete Cab Solution

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

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:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation in ( T_{ambient} )</td>
<td>&lt; 3°C</td>
</tr>
<tr>
<td>Average wind speed</td>
<td>&lt; 3.58 m/s</td>
</tr>
<tr>
<td>Average net downwelling IR</td>
<td>&lt; -85 W/m²</td>
</tr>
<tr>
<td>Variation in heater power</td>
<td>&lt; 15%</td>
</tr>
<tr>
<td>No precipitation</td>
<td>0 mm</td>
</tr>
</tbody>
</table>

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

\[
R = \frac{A}{UA}
\]

Relevance
Approach
Accomplishments
Collaborations
Future Work
UA Test Configurations & Results

43.0% Reduction in Sleeper UA with Complete Cab Solution

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

<table>
<thead>
<tr>
<th>Advanced Curtains &amp; Shades</th>
<th>Configuration</th>
<th>Reduction in UA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation</td>
<td>Standard</td>
<td>20.6%</td>
</tr>
<tr>
<td>Privacy Shades</td>
<td>Advanced</td>
<td></td>
</tr>
<tr>
<td>Sleeper Curtains</td>
<td>Advanced</td>
<td></td>
</tr>
</tbody>
</table>

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<th>Advanced Insulation</th>
<th>Configuration</th>
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</tr>
<tr>
<td>Sleeper Curtains</td>
<td>Standard</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Complete Cab Solution</th>
<th>Configuration</th>
<th>Reduction in UA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation</td>
<td>Advanced</td>
<td>43.0%</td>
</tr>
<tr>
<td>Privacy Shades</td>
<td>Advanced</td>
<td></td>
</tr>
<tr>
<td>Sleeper Curtains</td>
<td>Advanced</td>
<td></td>
</tr>
</tbody>
</table>
53.0% Reduction in Sleeper UA with Complete Cab Plus Solution

### Advanced+ Insulation

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Reduction in UA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation Advanced+</td>
<td>33.6%</td>
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<tr>
<td>Privacy Shades Standard</td>
<td></td>
</tr>
<tr>
<td>Sleeper Curtains Standard</td>
<td></td>
</tr>
</tbody>
</table>

### Advanced+ Insulation with Open Sleeper Curtains

<table>
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<th>Configuration</th>
<th>Reduction in UA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation Advanced+</td>
<td>21.6%</td>
</tr>
<tr>
<td>Privacy Shades Advanced</td>
<td></td>
</tr>
<tr>
<td>Sleeper Curtains - Open -</td>
<td></td>
</tr>
</tbody>
</table>

### Complete Cab Plus Solution

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Reduction in UA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation Advanced+</td>
<td>53.3%</td>
</tr>
<tr>
<td>Privacy Shades Advanced</td>
<td></td>
</tr>
<tr>
<td>Sleeper Curtains Advanced</td>
<td></td>
</tr>
</tbody>
</table>

**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

High-performance Computing (HPC) Server and Job Manager

Node 1

Node i

CoolCalc/HPC Interface
Accomplishment: Weather Locations

*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

Top 200 VMT Miles
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

Daily Cooling Thermal Load [kWh]

Relevance  Approach  Accomplishments  Collaborations  Future Work
Accomplishments: A/C Systems
Modeling Auxiliary Electric Sleeper System Performance

Discharge State

Battery Bank

HVAC System Inverter

AC System Model

Compressor
Evaporator Blower
Condenser Fan
Controller

Charge State

Vehicle Model

M Engine

Serpentine Belt Efficiency

M Alternator

External Voltage Regulator / Charging System

Battery Bank

Accessory Electrical Loads
Down-the-road Operation

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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
      \[ \approx 10 \text{kWh}_{\text{electric}} \text{ capacity} \]

- **Discharge assumptions**
  - Average annual COP
    \[ \text{COP}_{\text{AirCond}} = \frac{\text{Annual Cooling Load}}{\text{Annual Electric Power}} \approx 1.83 \]
  - Inverter efficiency 90%
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

<table>
<thead>
<tr>
<th>Date</th>
<th>Final SOC</th>
</tr>
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<tbody>
<tr>
<td>June 8</td>
<td>0.31</td>
</tr>
<tr>
<td>June 9</td>
<td>0.00</td>
</tr>
<tr>
<td>June 10</td>
<td>0.76</td>
</tr>
<tr>
<td>June 11</td>
<td>0.40</td>
</tr>
<tr>
<td>June 12</td>
<td>0.09</td>
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<tr>
<td>June 13</td>
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</tr>
<tr>
<td></td>
<td>0.67</td>
</tr>
</tbody>
</table>

*State of charge (SOC)*

Battery Charging Algorithm

\[ i_{battery} + i_{other} \]

Fuel Use Without Battery Charging

\[ P_{accessory} = i_{tot} \cdot V_{bus} \cdot \eta_{regulator} \cdot \eta_{alternator} \cdot \eta_{belt} \]

Vehicle Map

Battery Recharge Fuel Use

Autonomous

NATIONAL RENEWABLE ENERGY LABORATORY
Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm

Battery Charging Algorithm

\[ i_{battery} + i_{other} \]

Fuel Use Without Battery Charging

Alternator Map

\[ P_{accessory} = i_{tot} \times V_{bus} \times \eta_{regulator} \times \eta_{alternator} \times \eta_{belt} \]

Vehicle Map

Update Battery SOC

*State of charge (SOC)
Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm

*State of charge (SOC)
Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm

Battery Charging Algorithm

\[ i_{\text{battery}} + i_{\text{other}} \]

Fuel Use Without Battery Charging

\[ i_{\text{other}} \]

Alternator Map

Alternator Map

Vehicle Map

Vehicle Map

Battery Recharge Fuel Use

\[ P_{\text{accessory}} = i_{\text{tot}} * V_{\text{bus}} * \eta_{\text{regulator}} * \eta_{\text{alternator}} * \eta_{\text{belt}} \]

*State of charge (SOC)
Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm

- CoolCalc Modeling
- Fuel Use Estimation
- Battery Recharge Algorithm

Battery Charging Algorithm

Alternator Map

Fuel Use Without Battery Charging

Vehicle Map

\[ P_{\text{accessory}} = i_{\text{tot}} \cdot V_{\text{bus}} \cdot \eta_{\text{regulator}} \cdot \eta_{\text{alternator}} \cdot \eta_{\text{belt}} \]

*State of charge (SOC)
Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm

Battery Fully Recharged

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

\[ P_{\text{accessory}} = i_{\text{tot}} \times V_{\text{bus}} \times \eta_{\text{regulator}} \times \eta_{\text{alternator}} \times \eta_{\text{belt}} \]

Fuel Use Without Battery Charging

\[ i_{\text{battery}} + i_{\text{other}} \]

Alternator Map

Vehicle Map

Battery Recharge Fuel Use
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
- **June 11**
  - Final SOC = 0.09
- **June 12**
  - Final SOC = 0.27
- **June 13**
  - Final SOC = 0.67

*State of charge (SOC)*

**Battery Charging Algorithm**

\[ i_{\text{battery}} + i_{\text{other}} \]

**Fuel Use Without Battery Charging**

\[ P_{\text{accessory}} = i_{\text{tot}} \times V_{\text{bus}} \times \eta_{\text{regulator}} \times \eta_{\text{alternator}} \times \eta_{\text{belt}} \]

**Vehicle Map**

**Battery Recharge Fuel Use**
Accomplishments: CoolCalc Modeling—Fuel Use Estimation

Battery Recharge Algorithm

Daily Discharge Statistics

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</table>

*State of charge (SOC)*

Battery Charging Algorithm

![Battery Charging Graph]

Fuel Use Without Battery Charging

\[ i_{\text{other}} = i_{\text{battery}} + i_{\text{other}} \]

Alternator Map

![Alternator Map]

Vehicle Map

![Vehicle Map]

Vehicle Recharge Fuel Use

\[ P_{\text{accessory}} = i_{\text{tot}} \cdot V_{\text{bus}} \cdot \eta_{\text{regulator}} \cdot \eta_{\text{alternator}} \cdot \eta_{\text{belt}} \]
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)*
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

Accomplishments: Fuel Use Estimation

Cycle Weighting Fractions: 86%  9%  5%

Recharge Results

HVAC Load Profile

HVAC Energy

Fuel Use Impact

Accomplishments: Fuel Use Estimation
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*

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

Cumulative Savings

Years of Operation

1. TRLP (idling), $2.50/gal
2. TRLP (idling), $3.00/gal
3. TRLP (idling), $4.00/gal
4. TRLP + Electric A/C, $2.50/gal
5. TRLP + Electric A/C, $3.00/gal
6. TRLP + Electric A/C, $4.00/gal

Initial Investment (aftermarket estimate)

Cumulative Savings

Years of Operation

0 1 Year 2 Year 3 Year 4 Year 5 Year

Initial Investment (aftermarket estimate)
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)

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

![Energy Efficiency vs Ambient Temperature](chart)

---

**Preliminary Analysis**

![Average Fleet Efficiency vs Ambient Temperature](chart)

---

**Average Fleet Efficiency** [kWh/km]

**Average Ambient Temperature** [°C]
Collaboration

• 21st Century Truck Partnership
  • Kenworth
    o Fully instrumented and tested for thermal-load measurements
    o Developed, validated, and released CoolCalc model

• Volvo Trucks
  o Completed thermal testing
  o Developed and validated CoolCalc model,
  o CoolCalc model application in progress

• Daimler Truck, Super Truck Program
  o Completed thermal testing of Super Truck
  o Developed and validated CoolCalc model

• PPG Industries
  o Evaluated advanced paint technology

• Aearo Technologies LLC
  o Evaluated insulation packages

• Measurement Technology Northwest
  o Thermal manikin testing

• In discussion with several commercial vehicle partners for other vocations
## Responses to FY15 AMR Reviewer Comments
(for previous phase of project)

<table>
<thead>
<tr>
<th>Comment</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
<td>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.</td>
</tr>
<tr>
<td>The reviewer commented that the proposed future research is a logical progression that increases the value of this project's products.</td>
<td>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.</td>
</tr>
<tr>
<td>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.</td>
<td>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.</td>
</tr>
</tbody>
</table>
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

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

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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Jason.Lustbader@nrel.gov
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 Schroeder, NREL

• Slide 37
  1. Photograph of trucks on VTP, Cory Kreutzer, NREL
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)