2014 DOE Vehicle Technologies Office Review Presentation

ePATHS

Electric PCM Assisted Thermal Heating System

P.I. Dr. Mingyu Wang

Delphi Automotive Systems

June 19, 2014

Project ID # VSS136

ePATHS Overview

Timeline

- Start Date – Oct. 1, 2013
- End Date – Dec. 31, 2016
- Percent Complete – 5%

Budget

- Total project funding: $3.48M
  - DOE share: $1.74M
  - Contractor share: $1.74M
- Funding received in FY13: $0
- Funding for FY14: $1.03M

Barriers & Targets

- EV cold weather range +20%
- Phase Change Material (PCM) latent capacity +50%
- Vehicle integrated PCM heating and control system

Team/Partners

- *Ford Motor Company*
  - Vehicle reqm'ts & controls integration
- *Oak Ridge Nat'l Lab*
  - Simulation, design & cert. testing
- *Entropy Solutions*
  - High capacity PCM development
- *Project lead - Delphi*

Relevance: Support VTP Efforts

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- DOE Vehicle Technologies Program (VTP)
  - Reduce Petroleum usage and GHG emissions…
  - Requires "…new and more fuel efficient vehicle technologies."

- EV-Everywhere Grand Challenge
  - '… produce electric vehicles that are as affordable for the average American family as today's gas-powered vehicles within the next 10 years (by 2022). "
  - Driving range influences consumer acceptance

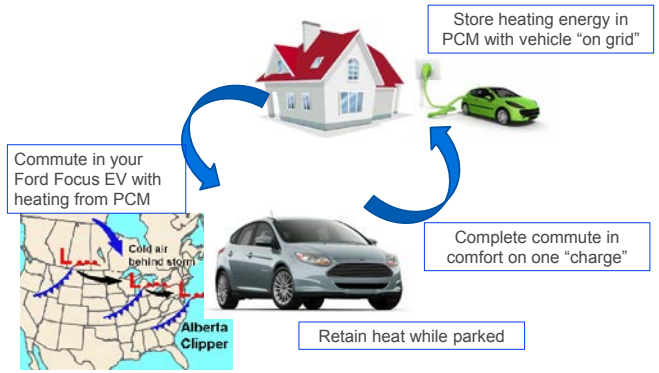
FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

- AOI-11 Advanced Climate Control Auxiliary Load Reduction
  - Advanced HVAC Technologies: increase range
  - "…innovative and unique heating…" using phase change materials

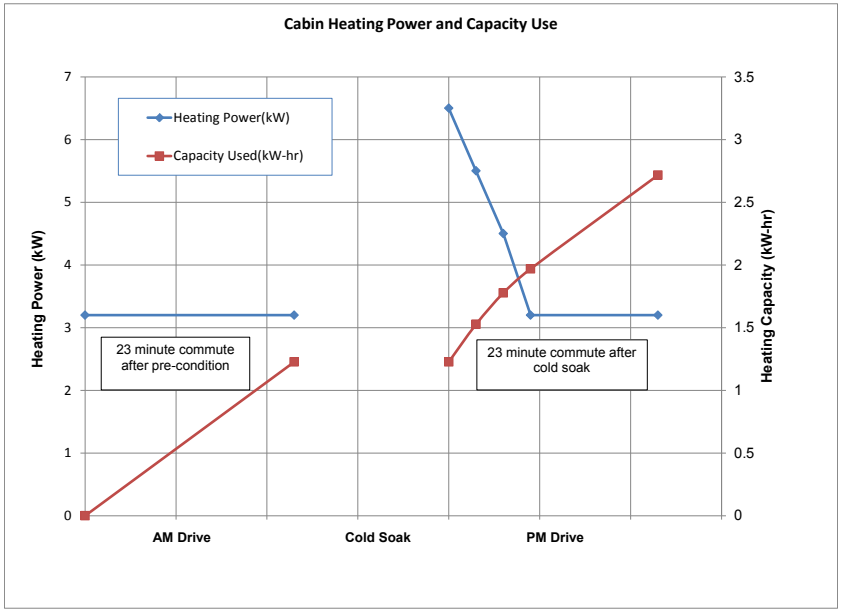
FOA DE-0000793

Relevance

- Extend GCEV range >20% by reducing or eliminating the auxiliary heating load from the vehicle battery @-10°C
- Develop “hot” PCM with >50% increase in latent heat capacity for industry application
- Develop simulation and optimization code for system and components
- Seamless vehicle integration with smart charging and discharging control
- Demonstrate performance and establish commercial viability



Typical Commute Usage Cycle



Representative Heating Demand

Project Execution - Milestones

- Budget Period 1 –Design/Development — Start 10/1/13, Finish 12/31/14
  - First Go / No-Go

Milestone	Type	Description
System Component Specifications Complete	Technical	The System and component specifications will be complete
Development Level Design Complete	Go/No Go	Development Level designs for the system and components completed and ready for build.

- Budget Period 2 – Development/Demonstrate — 1/1/15 12/31/15
  - Second Go / No-Go

Milestone	Type	Description
Thermal Energy Storage Demonstration	Go/No Go	Analysis validates that the system approach results in at least 20% increase in electric drive range vs. the baseline vehicle

- Budget Period 3 – Integration/Validation — 1/1/16 12/31/16

Milestone	Type	Description
Vehicle Integration System Complete	Technical	Integrated system testing completed and performance targets are achieved
Vehicle Testing Complete	Technical	Vehicle testing complete including evaluation of Thermal Performance, Charging Process, and Range Improvement.

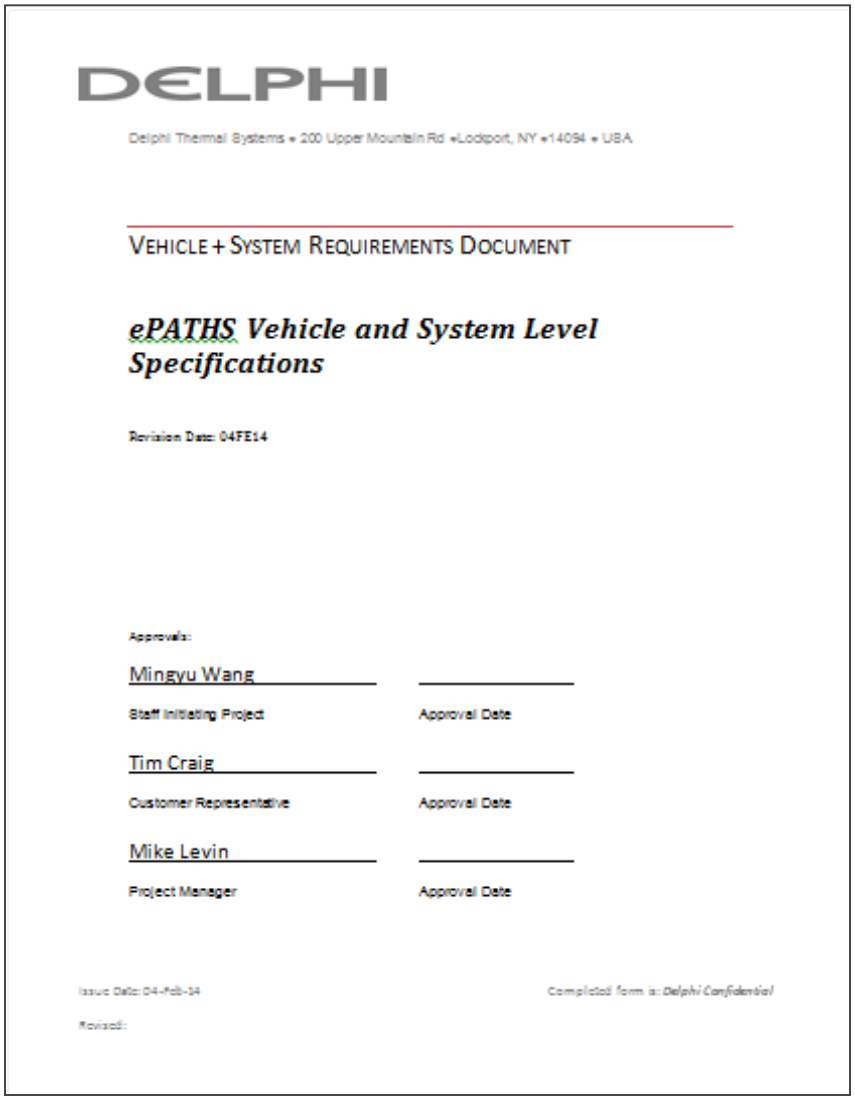
Approach/Strategy: Technical

- Working with OEM Partner Ford to identify vehicle level technical requirements (Ford, Delphi, ORNL)
  - Determine range certification test protocol
- Based on vehicle requirements, establish system and components specification (Team)
- Working with ORNL to establish system and components modeling-analysis capability (ORNL, Delphi)
- Establish system and components design, using analysis tool to achieve optimization (Delphi, ORNL)
- Establish controls hardware and software strategy (Delphi, Ford)
- Build and test bench system for proof of concept (Delphi, ORNL)
- Final system build and vehicle integration
- Perform range certification test at Delphi/ORNL

Technical Accomplishments and Progress - Specification

- **Objective**
  -Develop a Vehicle and System level Specification to define the vehicle interface and operating parameters for the ePATHS system in a light-duty BEV automotive vehicle.

- **Accomplishments and Progress**
  -Preliminary specification has been created and distributed to team for comment and updates
  -Included a Functional Description, Performance, Packaging, Durability, Interface, Quality and Service Requirement sections
  -Target to formalize completion of specification by May 1, 2013



DELPHI

Delphi Thermal Systems • 200 Upper Mountain Rd •Lockport, NY •14094 • USA

VEHICLE + SYSTEM REQUIREMENTS DOCUMENT

ePATHS Vehicle and System Level Specifications

Revision Date: 04FE14

Approvals:

Mingyu Wang _____ _____

Staff Initiating Project — Approval Date

Tim Craig _____ _____

Customer Representative — Approval Date

Mike Levin _____ _____

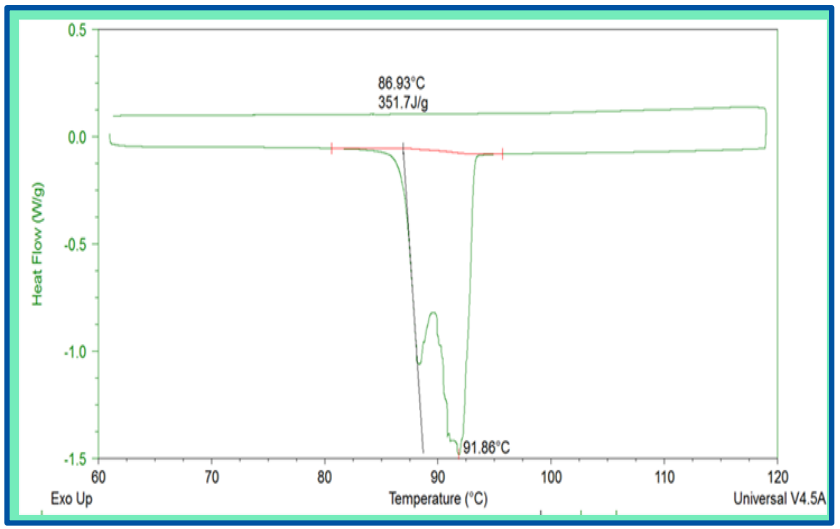
Project Manager — Approval Date

Issue Date: 04-Feb-14 — Completed form is: *Delphi Confidential*

Revised:

Technical Accomplishments and Progress - PCM

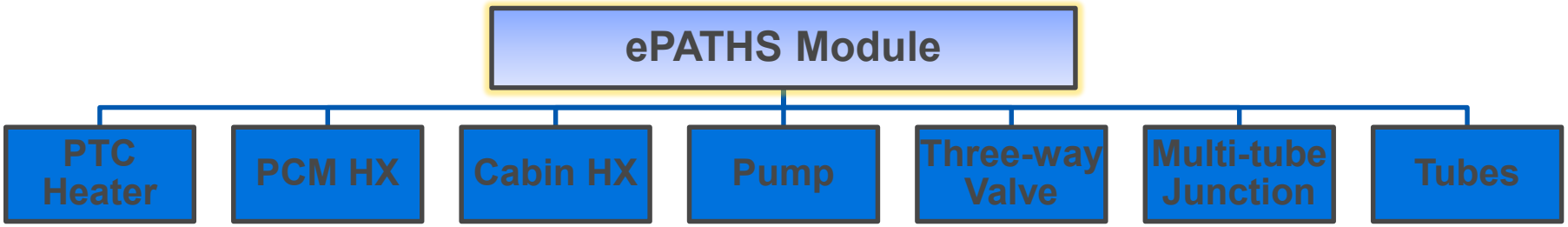
- **Objective**
  - Development of PCMs that undergo a phase change at 90–100°C with 350 J/g latent heat
- **Accomplishments and Progress**
  - Investigated 5 families of PCM candidates
  - Measured the phase change temperatures, latent heats, and thermal cycling properties of these families
  - Identified structural traits that will assist in the development of future PCMs
  - Identified a possible PCM that approaches our target goals (350 J/g, 90–100°C)



Entropy Solutions

Renewable Alternatives™ Advancing Technology with Nature's Products

Technical Accomplishments and Progress - ePATHS Model: ORNL



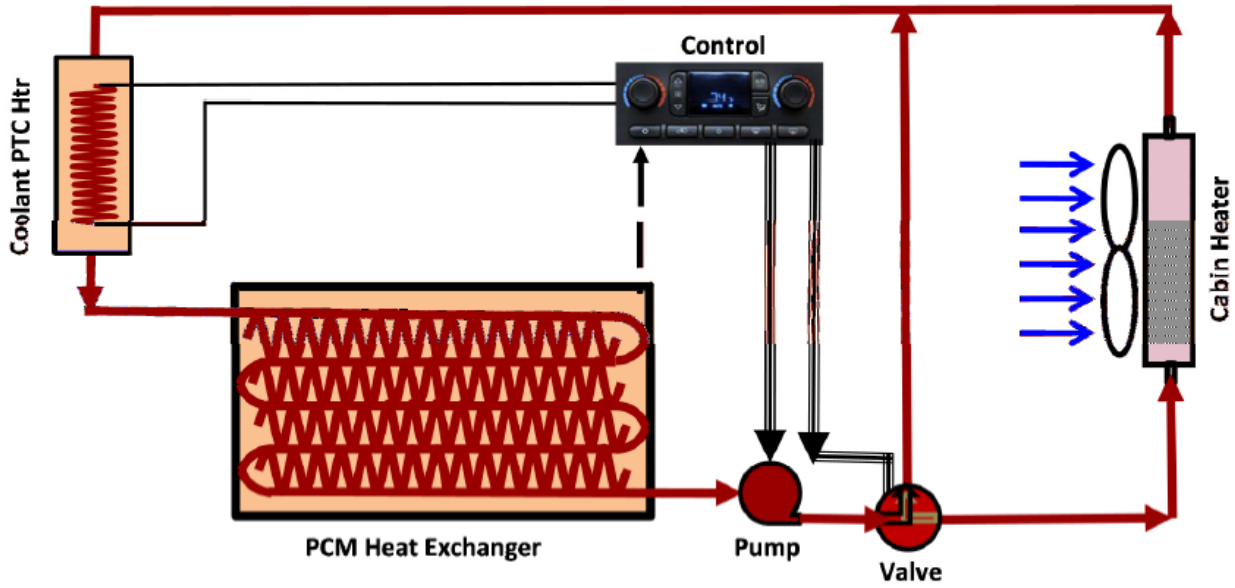
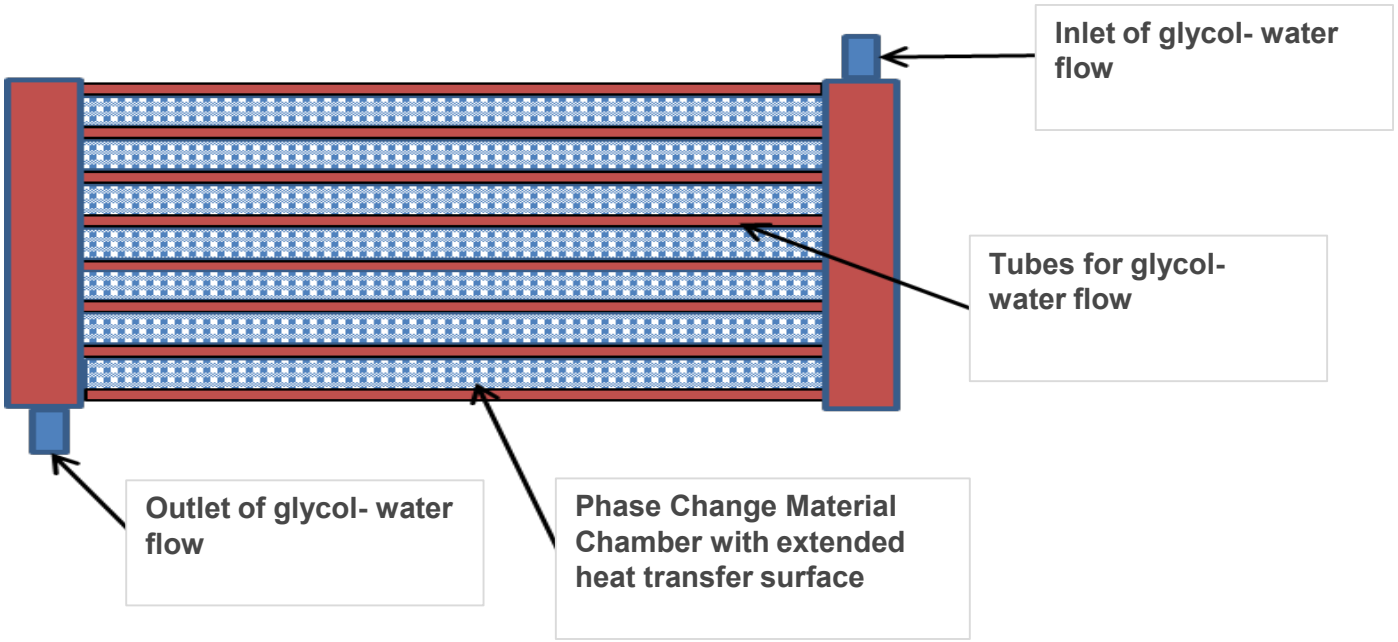


Figure 3 ePATHS System Design

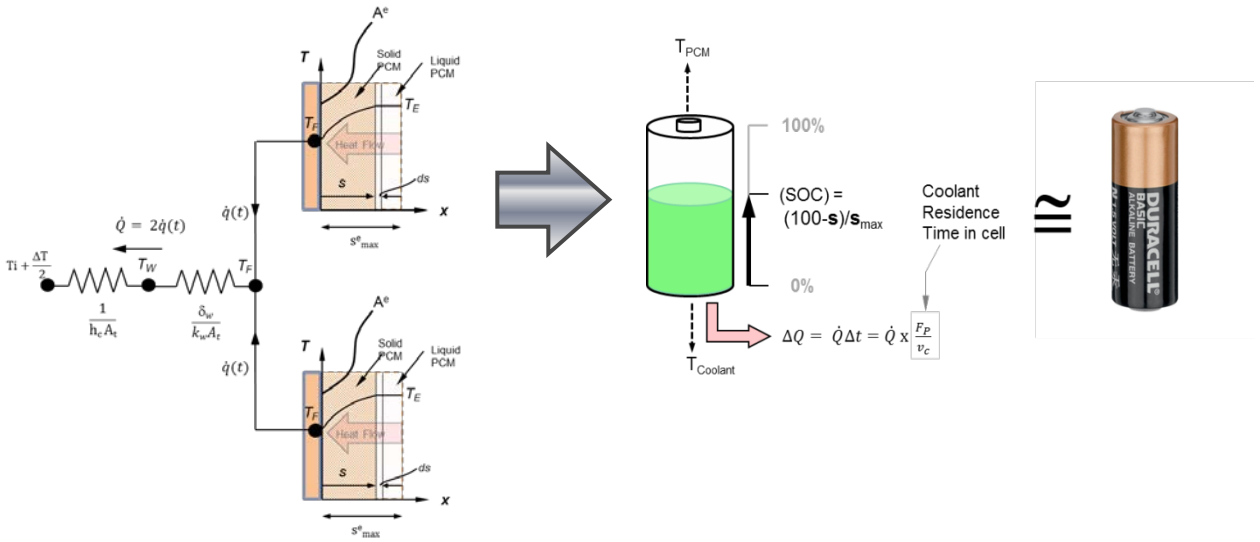
Technical Accomplishments and Progress - Heat Exchanger Design



ePATHS Heat Exchanger

- 2-Pass Coolant-to-PCM heat exchanger *similar* to automotive radiator
- A quarter-size prototype will be used to characterize Coolant-to-PCM heat exchange process

Technical Accomplishments and Progress - Heat Exchanger Analysis

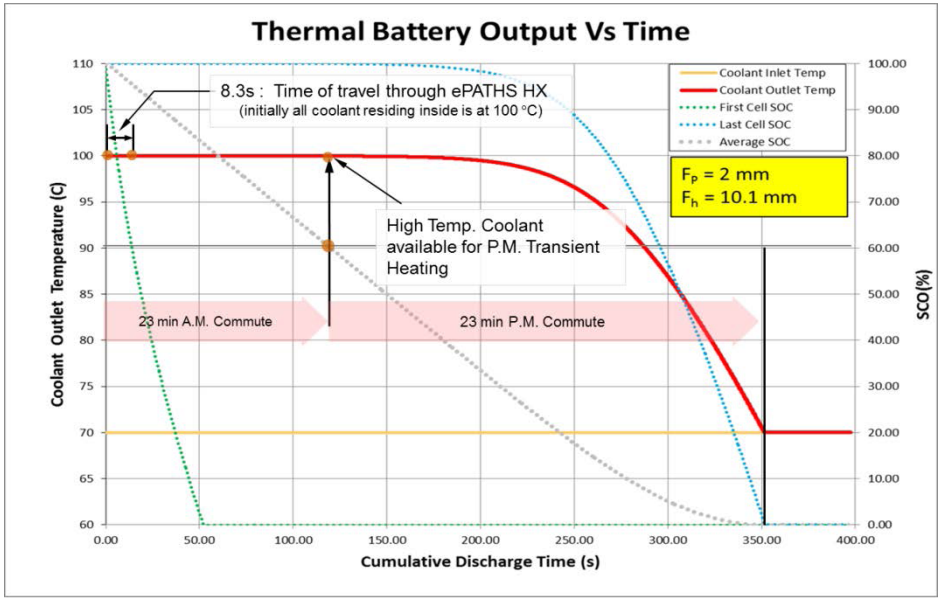


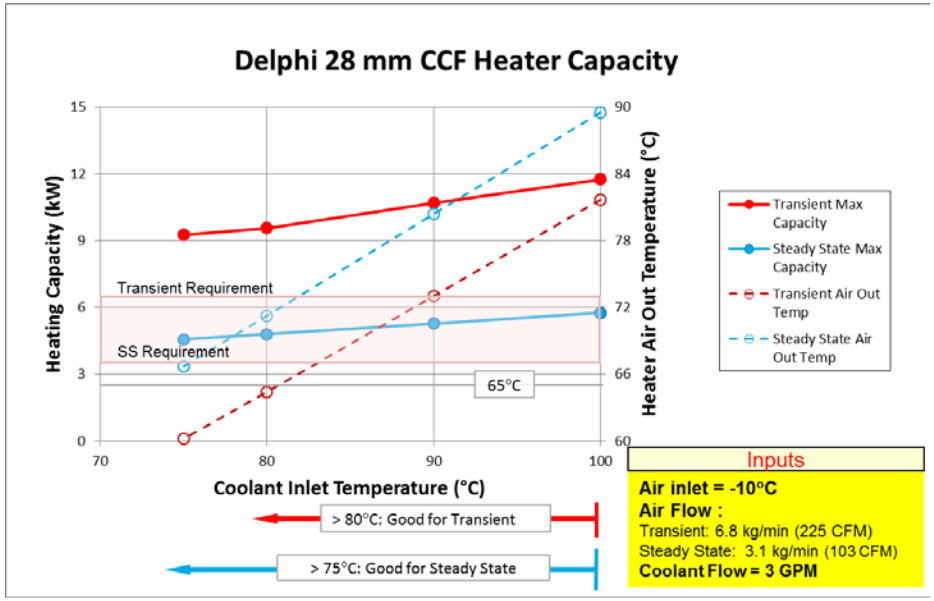
Simplified Thermal Resistance Model

Equivalent Thermal Battery Cell

- Thermal Unit represents the basic element of heat exchanger
- Thermal Unit is transformed into a simplified resistance network model to calculate heat flow and temperatures at each nodes
- More detailed resistance network is being analyzed by ORNL

Technical Accomplishments and Progress - Analysis Results





- Preliminary modeling of component heat exchangers indicate heating capacity and coolant temperature needed by HVAC heater will be met by the ePATHS heat exchanger
- Calculation of capacity reduction due to parasitic heat loss from ePATHS heat exchanger indicates about 10% of full capacity loss over 8 hrs. Team is developing heat loss and insulation to reduce losses.

Technical Accomplishments and Progress - Smart Charging Control

- Delphi Thermal custom developmental controller is targeted for control usage.
- 7 inch color touch screen interface for displaying / inputting system data and control values.
- Data can be logged on a PC with the correct software.
- Software and screens to be developed for this project.
- Automotive HVAC grade microcontroller.

IO Capabilities:

- 26 - 10 bit A/D Channels
- 8 - PWM outputs
- I2C Interface
- SPI Interface
- RS-232 communications

- Drives 12 DC motor actuators
- 8 - Timer Captures / Digital Inputs
- 4 - Digital Inputs
- 8 - Digital Outputs
- 2 - Digital I/O Ports

Collaboration

- **Delphi is lead organization**
  - Automotive experience
  - HVAC expertise
- **Strong Sub-recipient teams**
  - Ford – OEM
  - ORNL – Modeling
  - Entropy – Leading PCM technology
- **Experience of team members – many over 20 years in field**
- **Weekly project execution meeting**
  - Focus on task execution and timing
  - Resolve technical and resource issues
  - Communication

Future Work

- **Remainder of FY14 – Technology Design and Development**
  - Task 1.1.0 – System and Component Specifications
    - Subtask 1.1.1 – Vehicle Level Requirements
    - Subtask 1.1.2 – System Level Specifications
    - Subtask 1.1.3 – Component Level Specifications
  - Task 1.2.0 – Thermal Energy Storage System Design and Development
    - Subtask 1.2.1 – System Design and Development
    - Subtask 1.2.2 – Component Design
    - Subtask 1.2.3 – Initial Control System Design and Build
- **FY15: Technology Development and Demonstration**
  - Task 2.1.0 – Thermal Energy Storage System Development and Demonstration – Bench Level
  - Task 2.2.0 – Commercialization Plan
- **FY16: Technology Integration and Validation**

Summary

- **Team building and collaboration**
  - Site visit for face to face discussion
  - Strong technical interactions within team
- **Vehicle requirements and system specification**
  - Draft specification established
  - Team review in progress
- **PCM development**
  - Five families of PCM evaluated
  - One Candidate close to target capacity
- **System and PCM Heat Exchanger math model development**
  - PCM Heat Exchanger model established
  - System model established