# Unitary Thermal Energy Management for Propulsion Range Augmentation (UTEMPRA)

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*Delphi Automotive Systems, LLC*

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Project ID:VSS157

# Overview

## Timeline

Start Date: October 1, 2014
End Date: September 30, 2017

» Percent Complete: 12%

## Barriers

Severe Range Penalty of GCEDVs in Cold Weather (up to 40% range reduction at -10°C)

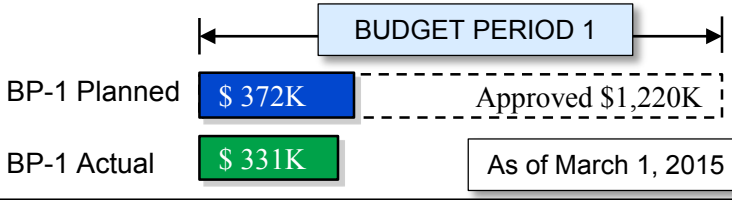
- Resistive heating is the typical heat source for passengers and battery – low-efficiency (COP<1.0) & significant drain on battery
- Must reduce customers' range anxiety for greater GCEDV acceptance

## Budget

Award No. : DE-EE0006840

Contract Value (80/20): $ 3,170,379

- Gov't Share (with National Lab) $ 2,536,303
- Delphi Team Share (with National Lab) $ 634,076




## Partners

FCA FIAT CHRYSLER AUTOMOBILES
NORGREN
NREL NATIONAL RENEWABLE ENERGY LABORATORY

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(Primary Awardee)

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# Relevance and Project Objective

## Overall Objective

UTEMPRA targets to **increase 15% BEV drive range at -10°C** with equivalent cabin comfort

- Scavenge waste heat from electronics and electric motor
- Provide thermal management to all power components
- Implement a simplified A/C and Heat Pump System with flexible coolant-based distribution
  - Coolant-based system can be synergized with with other energy-saving technologies (e.g. PCM-based thermal storage)
- Demonstrate technology for a 2015MY BEV with an OEM partner (FCA) to calculate energy benefit. Develop system for mass production by 2020. Bring project TRL from 3 to 7

## Specific Annual Objectives

- **Budget Period 1 (Oct. 1st -14 to Oct. 31st -15): Technology Development Phase**
  - » Program management & sub-contracts with partners
  - » Review vehicle requirements & develop system specification, explore vehicle packaging
  - » Instrument & test baseline vehicle to set performance targets
  - » Design system components (Heat exchangers, Compressor, Valves, Pumps)
  - » Develop flux-less braze equipment specification & order equipment (long-lead)
  - » Develop Matlab-Simulink system model to study Baseline and UTEMPRA systems

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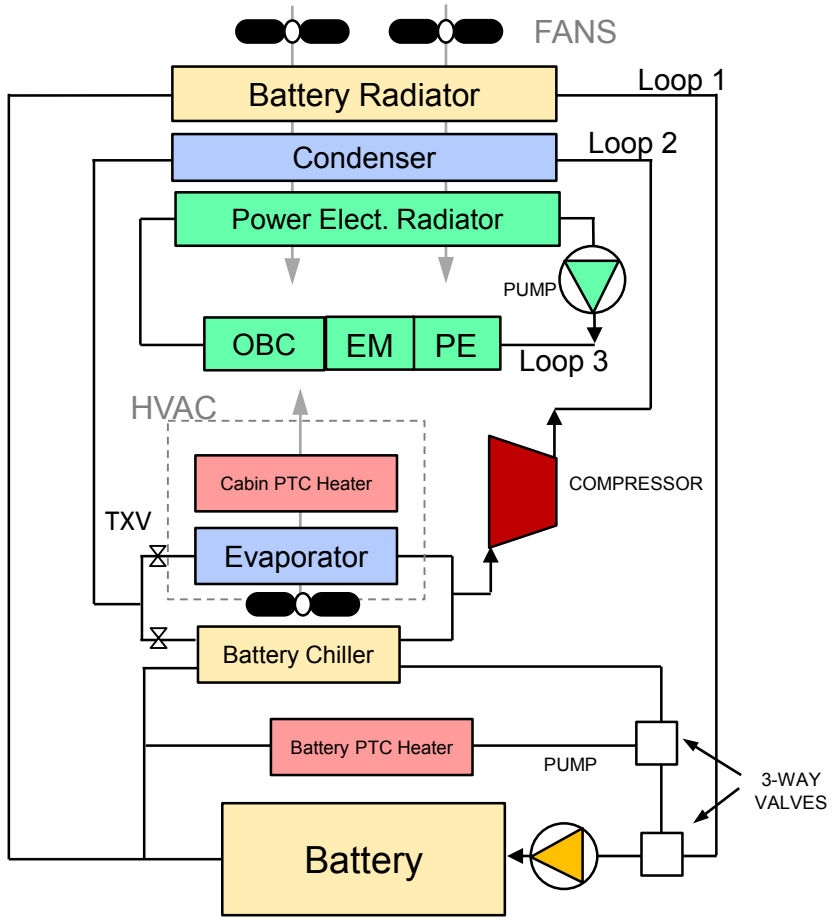
# Approach – Baseline BEV System

## 2015MY Fiat 500e BEV

- Cooling: Traditional Direct A/C System
  Heating: PTC (Resistive) Heater (qty. 2)
- Thermal Conditioning of Battery, Power Electronics and Cabin are independent
- Two PTC (Resistive) Heaters for the Cabin and Battery - significant drain on the battery
- Relatively simple control but no heat recovery/thermal optimization applied




2015 Fiat 500e Thermal Management System

*OBC – On-board Charger*
*EM – Electric Motor (Vehicle Propulsion)*
*PE – Power Electronics (Inverter)*

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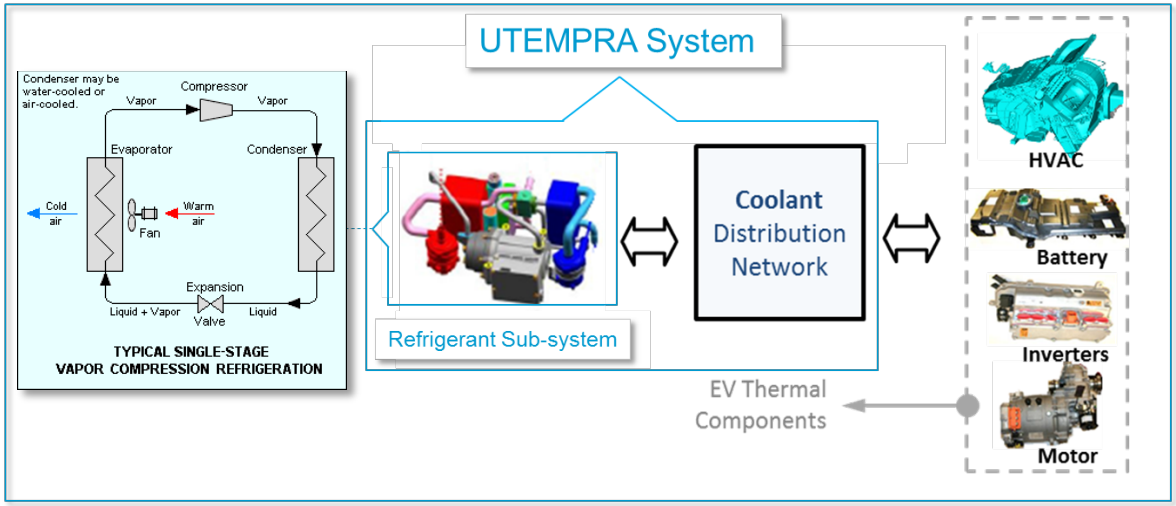
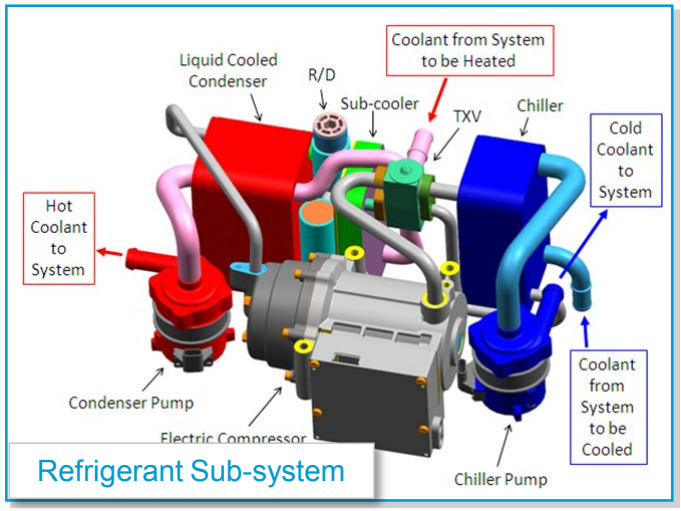
# Approach – UTEMPRA System

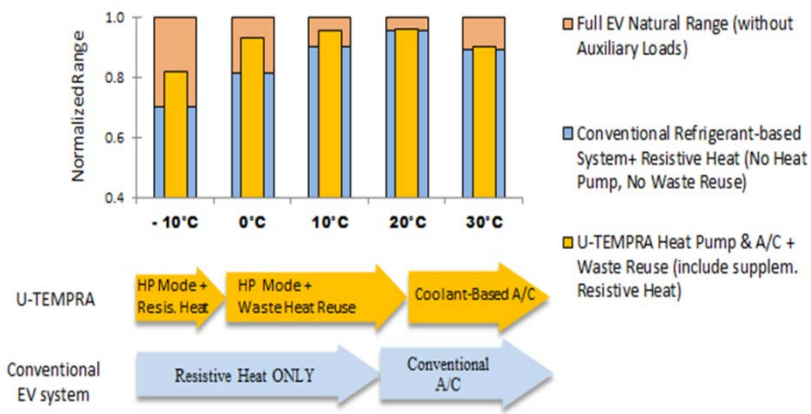



## UTEMPRA Benefits

- Compact refrigerant sub-system generates heating and cooling – continuously available and deployable
- Coolant architecture enables heat scavenging – improved fuel economy
- Coolant-based heat pump system is more simple and more flexible vs. refrigerant-based heat pump systems
- Significant refrigerant savings (est. 50% vs. ref. based heat pump systems) – cost and environmental benefit

## Expected Range Improvement

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# Approach – Milestones

| Date | Milestone | Status |
|---|---|---|
| Nov-14 | Milestone 1: Rough Vehicle Packaging Study | Complete (Dec-15) |
| Feb-15 | Milestone 2: System Specification | Complete (Mar-15) |
| Apr-15 | Milestone 3: Component Design | *Est. May-15* |
| Jul-15 | Milestone 4: Proof-of-Concept (POC) Manifold and Valve Design | *On Track* |
| Oct-15 | Milestone 5 and Go-No-Go 1: POC Manifold and Valve Build | *On Track* |

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# Approach – Activity Flow/Timeline

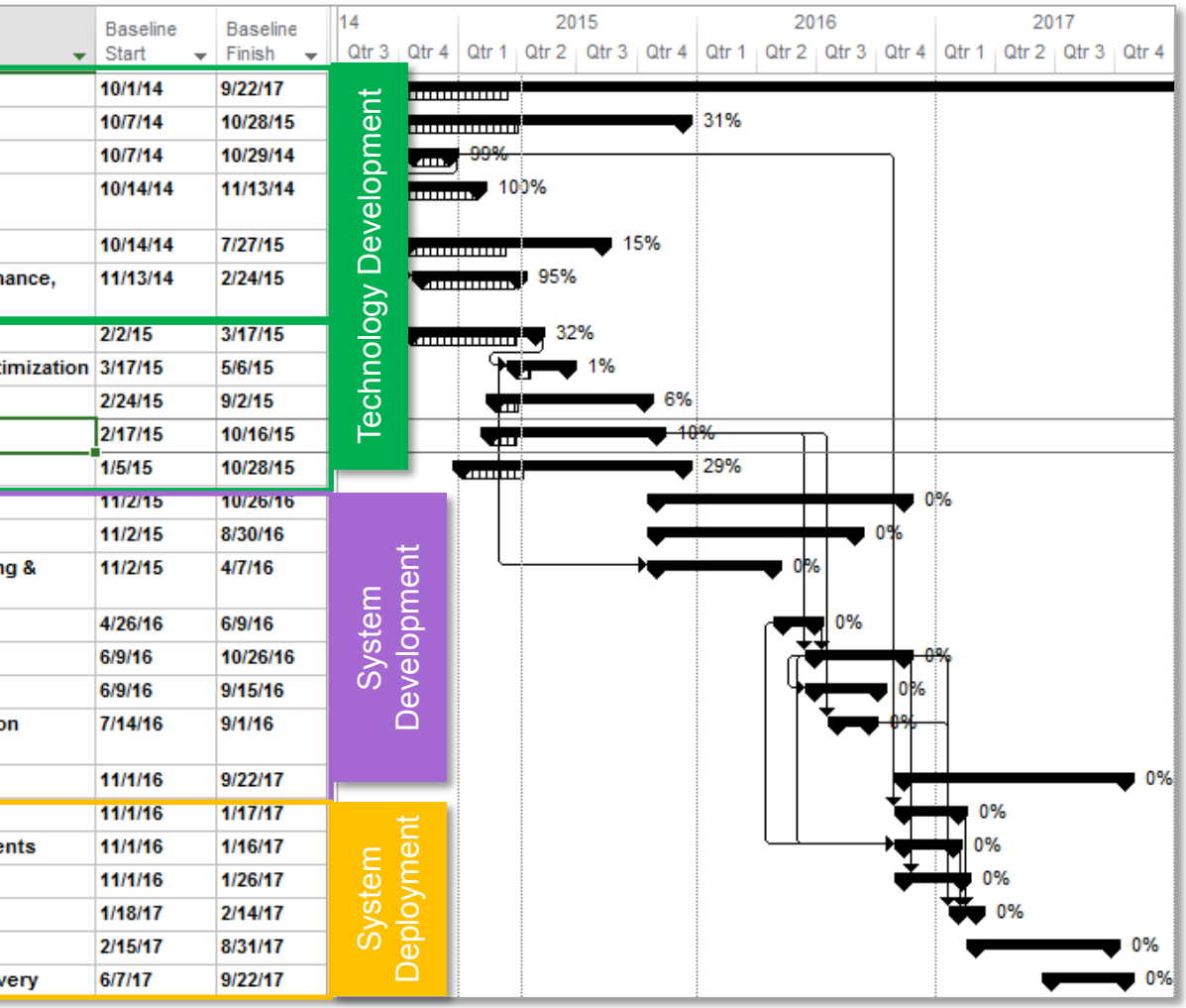
Mostly Complete

| | Task Name | Baseline Start | Baseline Finish |
|---|---|---|---|
| 0 | PMP & NREL | 10/1/14 | 9/22/17 |
| 1 | Budget Period 1 | 10/7/14 | 10/28/15 |
| 1.1 | Vehicle Requirements | 10/7/14 | 10/29/14 |
| 1.2 | Refrigerant, Lubricating Oil, Coolant & Compressor Selection | 10/14/14 | 11/13/14 |
| 1.3 | Vehicle CAD Data | 10/14/14 | 7/27/15 |
| 1.4 | Vehicle Baseline Tests (HVAC Performance, Energy Usage, Range Effect) | 11/13/14 | 2/24/15 |
| 1.5 | System & Component Specifications | 2/2/15 | 3/17/15 |
| 1.6 | Heat Exchanger Design, Analysis & Optimization | 3/17/15 | 5/6/15 |
| 1.7 | Unitary System Vehicle Modeling | 2/24/15 | 9/2/15 |
| 1.8 | Flow Control (Coolant) | 2/17/15 | 10/16/15 |
| 1.9 | Brazing Equipment Spec and Order | 1/5/15 | 10/28/15 |
| 2 | Budget Period 2 | 11/2/15 | 10/26/16 |
| 2.1 | Prototype Design / Build | 11/2/15 | 8/30/16 |
| 2.2 | Brazing Equipment Qualification, Tooling & Component Build | 11/2/15 | 4/7/16 |
| 2.3 | Component & System Tests | 4/26/16 | 6/9/16 |
| 2.4 | System Bench Performance Tests | 6/9/16 | 10/26/16 |
| 2.5 | Vehicle Controls Study | 6/9/16 | 9/15/16 |
| 2.6 | Human Machine Interface or Information Display | 7/14/16 | 9/1/16 |
| 3 | Budget Period 3 | 11/1/16 | 9/22/17 |
| 3.1 | Vehicle Controls | 11/1/16 | 1/17/17 |
| 3.2 | Design Durability Validation - Components | 11/1/16 | 1/16/17 |
| 3.3 | Manufacturing Plan & Cost Estimates | 11/1/16 | 1/26/17 |
| 3.4 | Vehicle Build | 1/18/17 | 2/14/17 |
| 3.5 | Vehicle Testing | 2/15/17 | 8/31/17 |
| 3.6 | Final Technical Analysis & Vehicle Delivery | 6/7/17 | 9/22/17 |

Technology Development

System Development

System Deployment




- Status (as of April 10th): approximately 1 month behind baseline schedule

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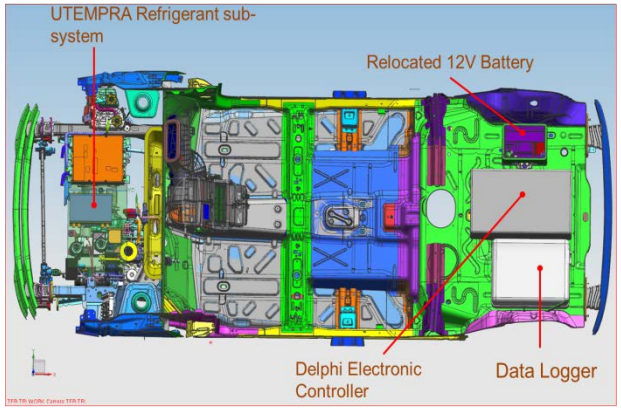
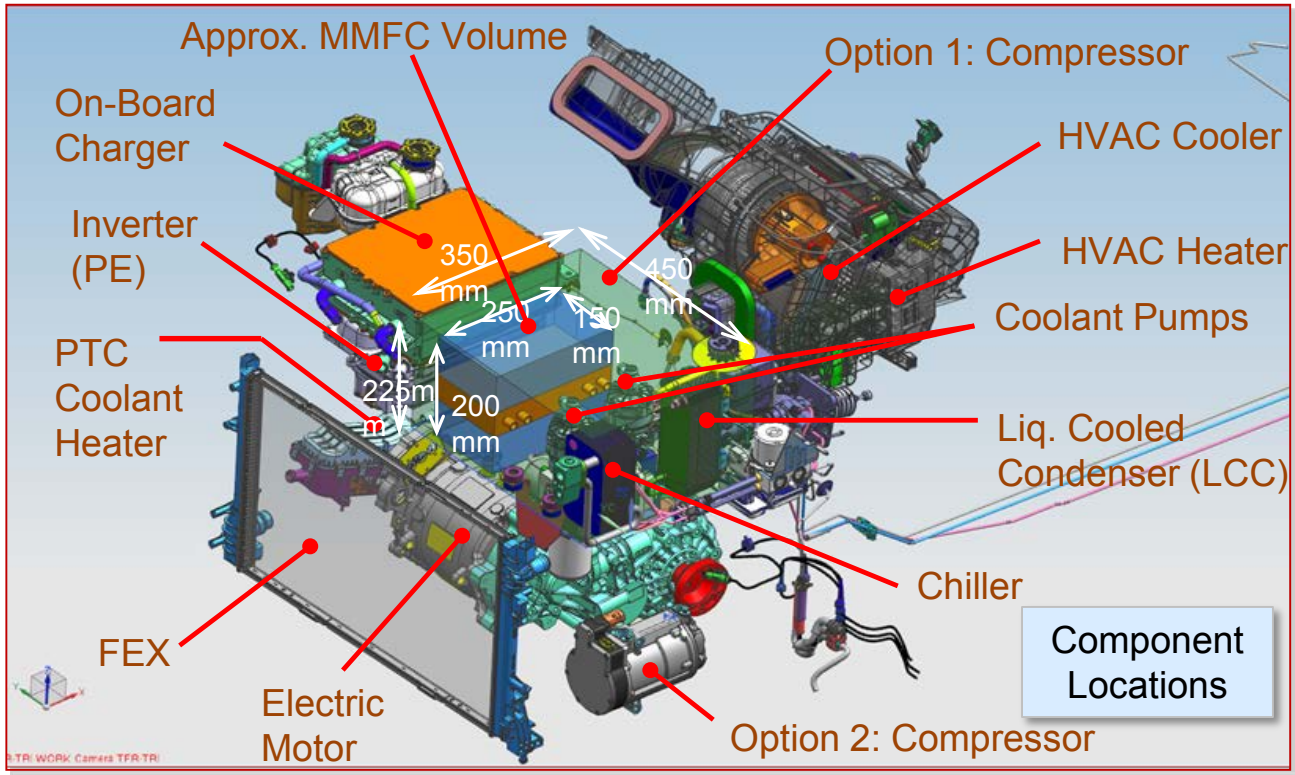
# Technical Accomplishments – Preliminary Vehicle Packaging Study




500e Top View




## UTEMPRA Packaging

- Very compactly packaged baseline vehicle under-hood
- Main UTEMPRA components are: Refrigerant-subsystem, Multi-mode Flow Controller (MMFC), Front-end Heat Exchanger
- Some existing components (12V battery, fuse box, electrical lines etc.) will be relocated to accommodate UTEMPRA components

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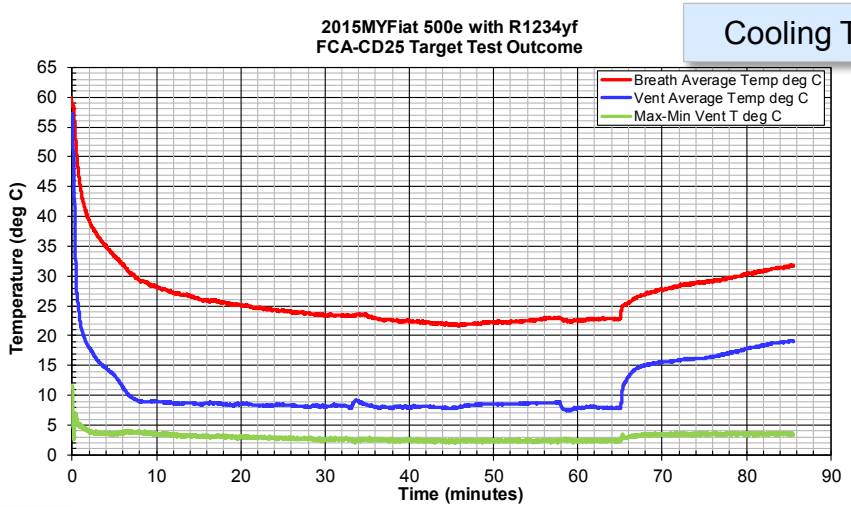
# Technical Accomplishments – Baseline Testing & Specification Creation

Cooling Test



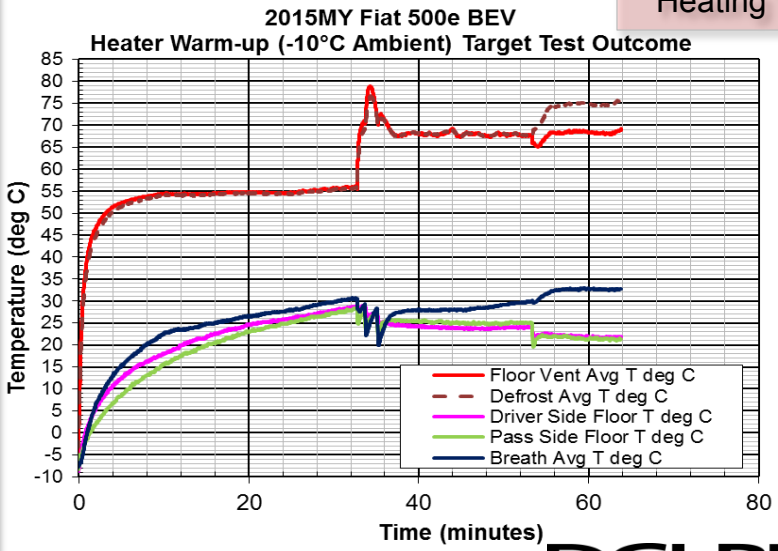

## Baseline Fiat 500e Testing Highlights

- R134a refrigerant (production) changed to R1234yf for UTEMPRA system
- FCA-provided iBox used to read vehicle CAN data traffic – *Battery internal temperature, power draw etc.*
- Heating and Cooling performance targets set based on FCA test procedures
- Automatic Climate Control (ACC) tests conducted to understand vehicle controller behavior

  ACC Heating : -10°C, 0°C, 20°C

  ACC Cooling: 25°C, 35°C, 43°C

Heating Test

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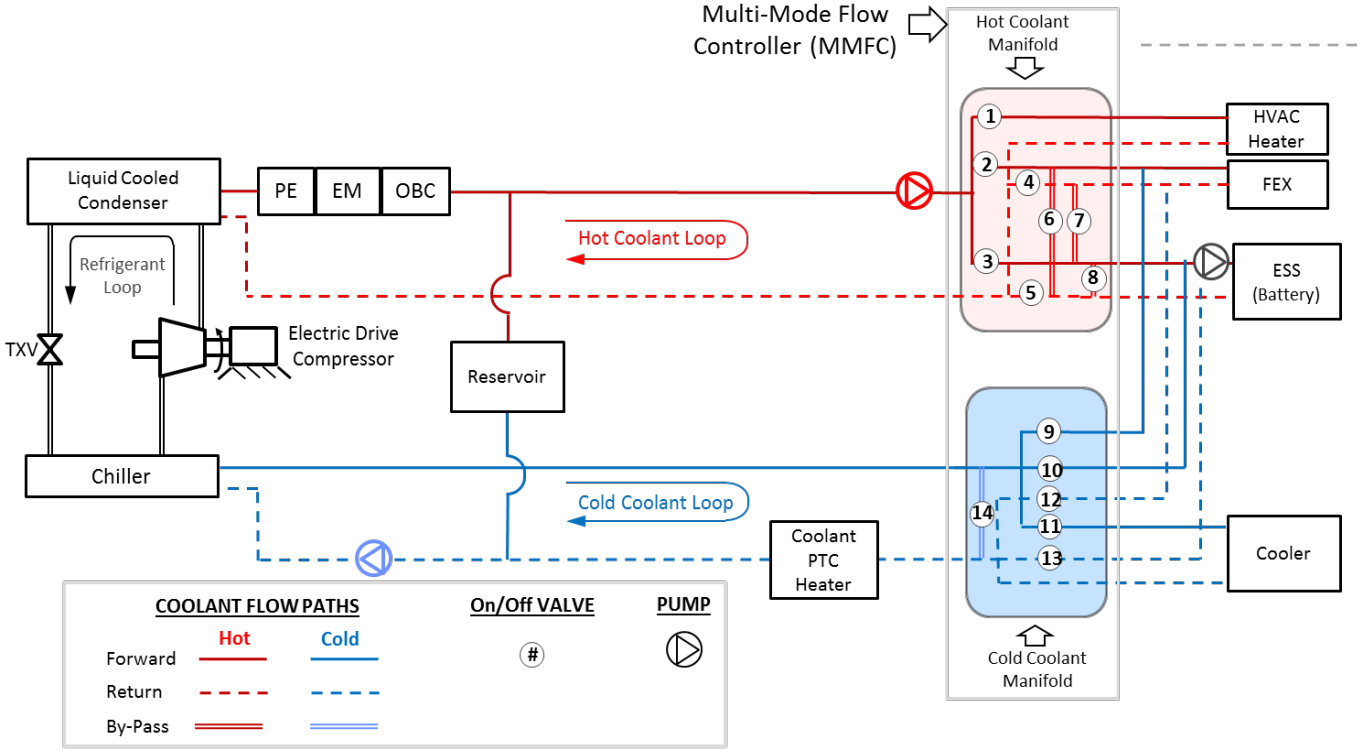
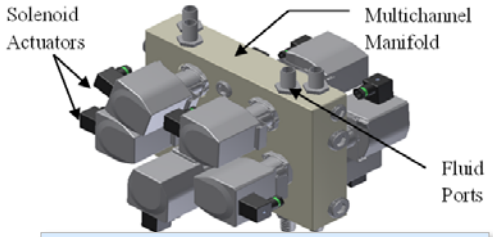
# Technical Accomplishments – Coolant System Architecture




Sample MMFC Design

## Proof-of-Concept (POC) Coolant System

- Total of 22 modes identified – encompassed all thermal functions in baseline vehicle plus heat pumping and heat scavenging
- POC MMFC design provides flexibility for technology development. Further refinement/consolidation of architecture planned in BP-2

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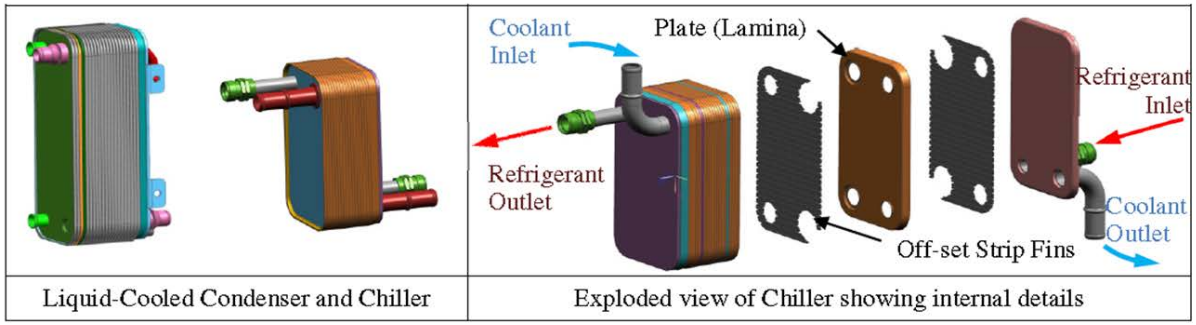
# Technical Accomplishments - Braze

**Concerns/issues with traditional brazing that require fluxing :**

- Because of compact design and internal braze surfaces residual flux will be present
  - » Coolant may react with residual flux producing corrosive by-products.
  - » Potential Safety Issue for battery and PEEM coolant circuits!
- Difficult to limit internal flux for laminated heat exchangers (multiple large heat exchangers)
  - » Possibility of product defect
  - » Cost

Flux-less brazing material solves these issues by eliminating fluxing
» Need to develop material and braze process




Liquid-Cooled Condenser and Chiller | Exploded view of Chiller showing internal details

UTEMPRA Laminated Heat Exchangers

Sectional View of Laminated Heat Exchangers

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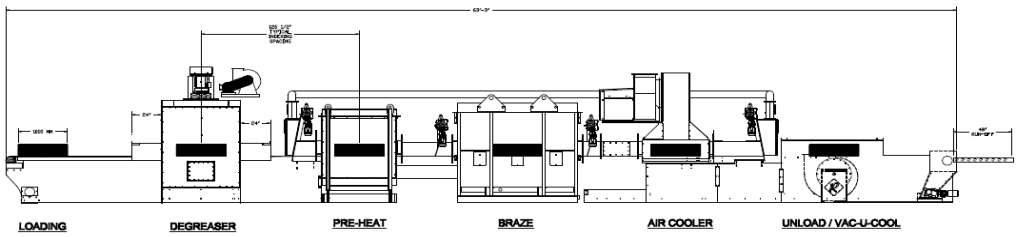
# Technical Accomplishments – Braze Furnace

- Flux-less material requires specific furnace environment to prevent the oxide layer from re-forming
  - » Desired $O_2$ levels approximately10-15 ppm
  - » Furnace must be clean and free from contamination from brazing traditionally fluxed products
- Existing production furnaces do not provide necessary braze zone height, cleanliness nor purity of environment
  - » UTEMPRA heat exchangers have large height and requires taller muffle of furnace
  - » Developmental furnace is required and included in this project
- Sourcing and ordering furnace equipment has a long lead time
  - » Equipment to be ordered in May, 2015
  - » Equipment delivery December, 2015

Similar 5-Zone Furnace

UTEMPRA Furnace Plan

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# Technical Accomplishments - Modeling

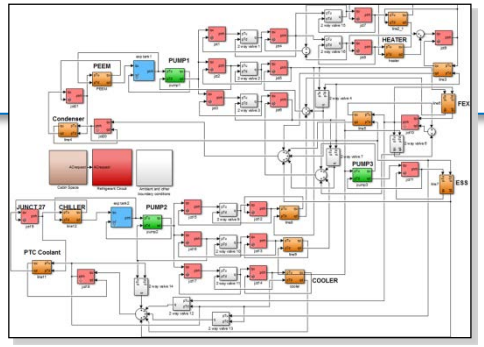
## Modeling Objectives:

- Create Baseline and UTEMPRA system & vehicle model
- Analyze system behavior to understand control system design requirements
- Understand impact of changes in component design

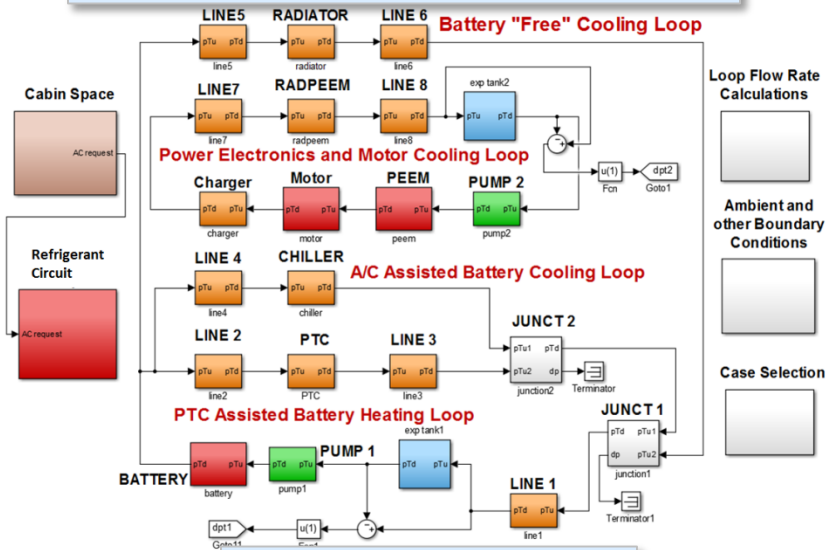
## Achievements:

- Matlab-Simulink-based Model has been initiated in February 2015 and is on-going
- Preliminary UTEMPRA model has been initiated. Detailed work on this model will occur in BP-1 (2nd half)

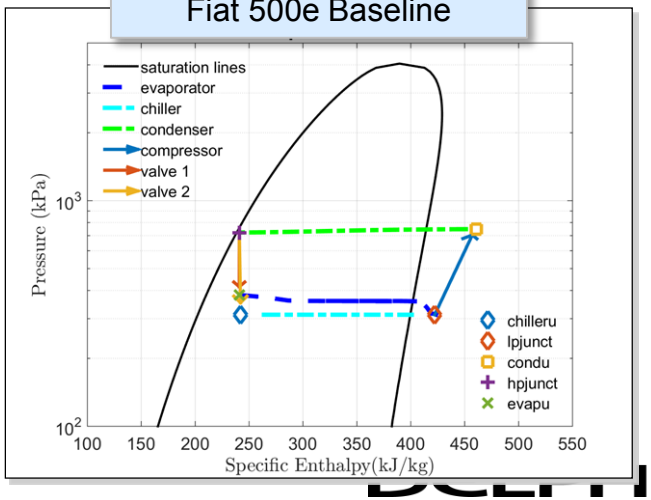
UTEMPRA Model under development



NREL Baseline Fiat 500e Model (CoolSIM)




Fiat 500e Baseline



# Response to Previous Years Comments

*N/A as this project is new*

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# Collaboration/Coordination with Subrecipients

- **FCA – Fiat Chrysler Automobiles (formerly Chrysler Group LLC), Auburn Hills, MI**
  - Responsible for providing BEV, packaging information, HVAC & PTC algorithm understanding and access
  - Responsible for vehicle range verification tests
- **Norgren, Inc. division of IMI (Farmington, CT)**
  - Design and develop MMFC (Multi-Mode Flow Controller)
  - Goal of commercially viable product
- **NREL – National Renewable Energy Laboratory, Golden, CO**
  - Responsible for thermal model of Unitary HPAC System
  - Responsible for vehicle thermal model
  - Bench test of the UTEMPRA system

- Coordination is accomplished through bi-weekly team meetings working from master timeline
- Separate collaboration sessions by teleconference
- Site visits/workshops planned in 2nd half of BP-1 onwards

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# Remaining Challenges and Barriers

- Challenge 1: Design and validate a Multimode Fluid Controller (MMFC) – “heart” of coolant network
  - Control all operating modes successfully
  - Meet mass & packaging
  - Make product commercially viable
- Challenge 2: Develop a braze recipe for flux-less braze materials
  - Minimize coolant contamination to protect battery and other sensitive HV components
  - Outline critical parameters for flux-less material braze
  - Identify possible braze issues in production
- Challenge 3: Integrate UTEMPRA system with existing ESS, PEEM and HVAC components in the Fiat 500e vehicle
  - Understand system compatibility issues (hardware/software) and control requirements of vehicle
  - Control UTEMPRA while communicating with the vehicle bus
  - Ensure safe operation of the vehicle with new (UTEMPRA) system
  - Determine drive cycles to best demonstrate the impact of UTEMPRA
    (SAE J1643 Recommended Practices available)

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# Future Work

- **Budget Period 1- Remainder (Apr. 10th to Oct. 31st -15): Technology Development Phase**
  - » Design system components (Heat exchangers, Compressor, Valves, Pumps)
  - » Develop flux-less braze equipment specification & order equipment (long-lead)
  - » Develop Matlab-Simulink system model to study Baseline and UTEMPRA systems

- **Budget Period 2 (Nov. 1st -15 to Oct. 31st -16): System Development Phase**
  - » Braze Equipment Qualification
  - » Component Tooling and Build
  - » Component and System Tests
  - » Prototype MMFC build and Test

- **Budget Period 3 (Nov. 1st -16 to Sep. 30th -17): Technology Deployment Phase**
  - » Vehicle Controls Development – Software/Hardware
  - » Durability Validation of Components
  - » Manufacturing Plan and Cost Estimation
  - » Vehicle Build with final components
  - » Vehicle Wind Tunnel and on-road testing
  - » Final Technical Analysis, Reporting, Vehicle Delivery to DOE

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# Summary of Key Achievements

- Established packaging feasibility and sizing guideline for UTEMPRA components
- Vehicle requirements, battery/power inverter thermal management logic and baseline vehicle testing together provided UTEMPRA requirements. Specification document (ver. 1) established.
- Coolant system architecture established. This provides design inputs for MMFC design and captured in MMFC Specification document.
- Braze furnace specification completed. Quotation is in process. Delivery and braze process qualification is a long lead time task.

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