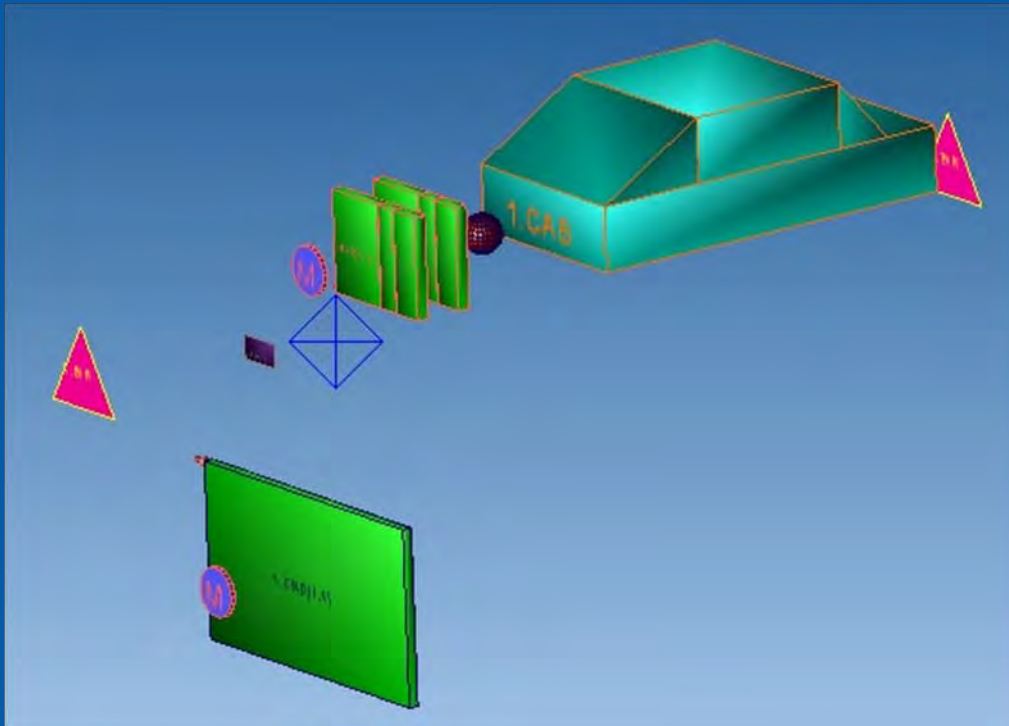


Integrated Vehicle Thermal Management – Combining Fluid Loops in Electric Drive Vehicles



U.S. Department of Energy
Annual Merit Review

National Renewable Energy Laboratory

PI: John Rugh

Tuesday May 10, 2011

Project ID: VSS046
APE038

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

Overview – Integrated Vehicle Thermal Management (IVTM)

Timeline

- Project start date: FY11
- Project end date: FY13
- Percent complete: 10%

Budget

- Total project funding
 - DOE share: \$375k
 - Contractor share: \$0
- FY11 Funding: \$375k

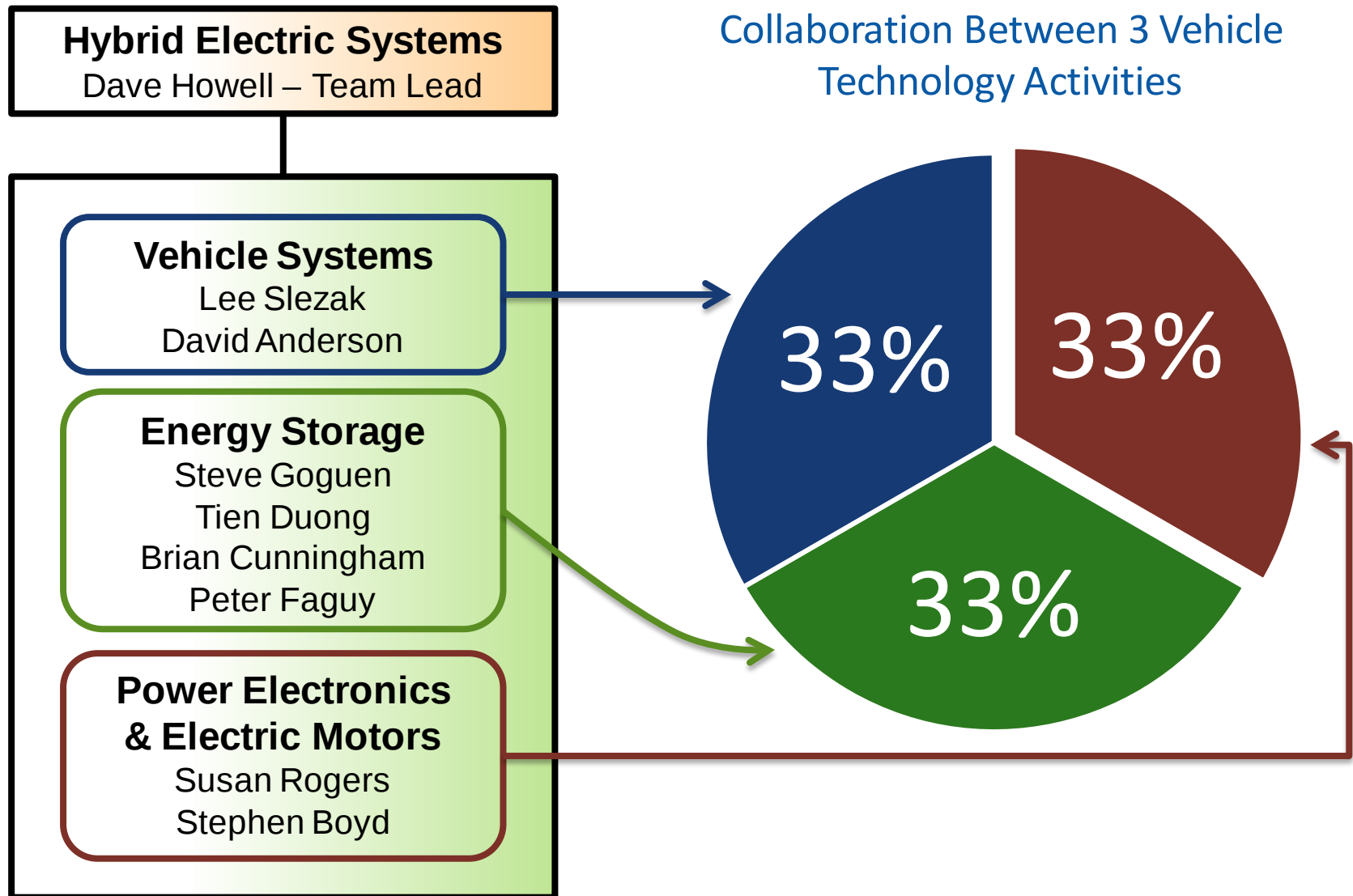
Barriers

- Cost – *cooling loop components*
- Life – *thermal effects on energy storage system (ESS) and advanced power electronics and electric motors (APEEM)*
- Weight – *additional cooling loops in electric drive vehicles (EDVs)*

Partners

- Interactions
 - Visteon
- Project lead: NREL

IVTM – FY11 Funding Overview, \$375k



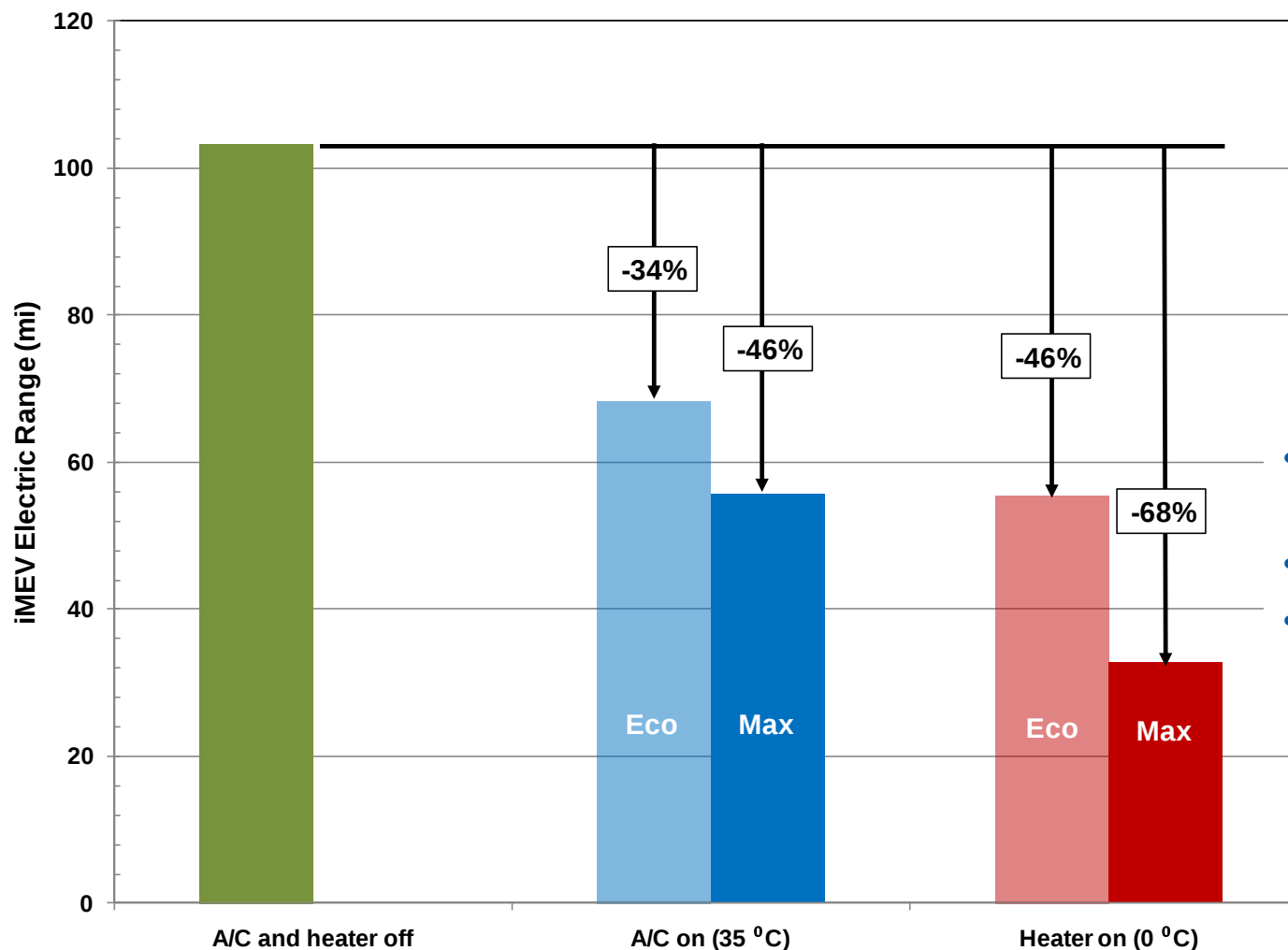
Relevance – The PHEV/EV Thermal Challenge

- Plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs) have increased vehicle thermal management complexity
 - Separate coolant loop for APEEM (advanced power electronics and electric motors)
 - Thermal requirements for ESS
- Multiple cooling loops may lead to reduced effectiveness of fuel-saving control strategies
 - Increased, weight, volume, aerodynamic drag, and fan/pump powers
 - Reduced electric range
- Cross-cutting system designs are challenging, involving separate teams at OEMs and suppliers



Photo Credit: Mike Simpson, NREL

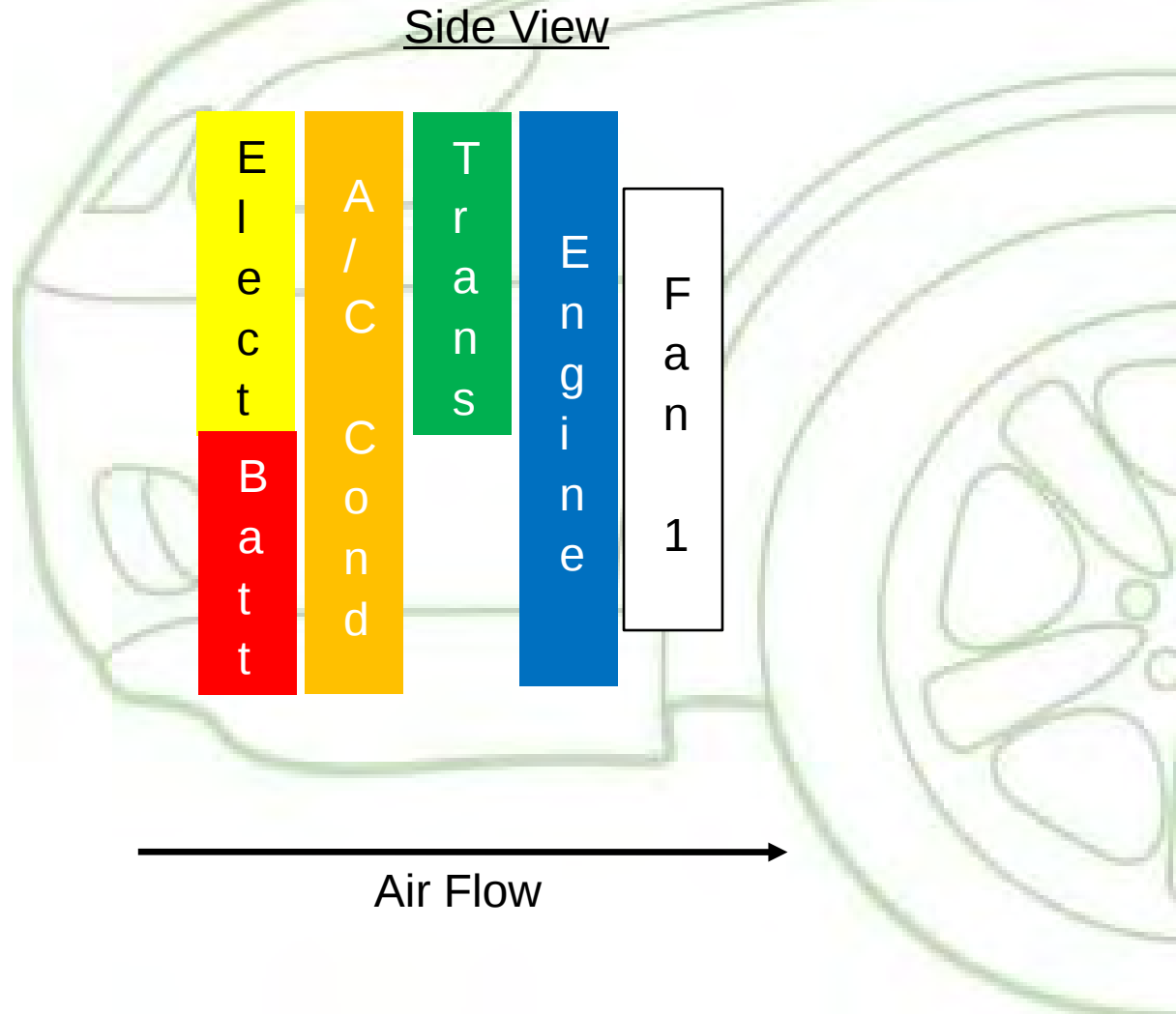
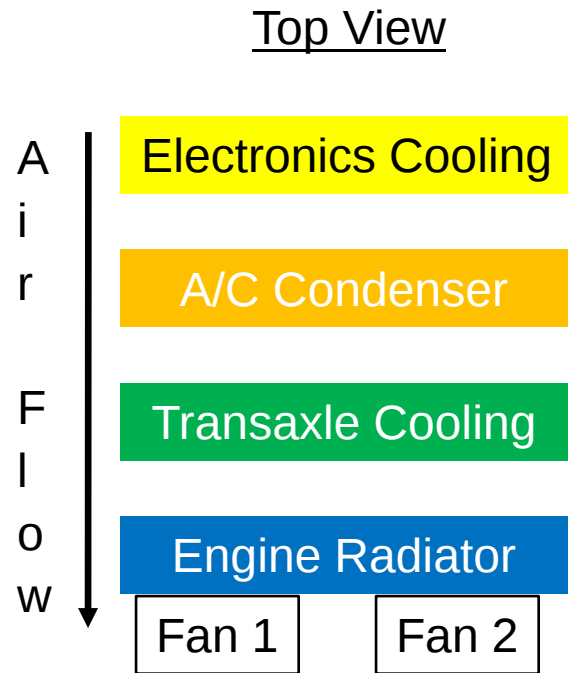
Relevance – Passenger Compartment A/C and Heating Significantly Impact EV Range



- Vehicle: Mitsubishi iMEV
- Drive Cycle: 10-15
- Impact on range
 - A/C: -34 % to -46%
 - Heating: -46% to -68%

Data Credit: Kohei Umezu and Hideto Noyama, Mitsubishi, Presented at the 2010 SAE Automotive Refrigerant and System Efficiency Symposium
Photo Credit: Mike Simpson, NREL

Relevance – Multiple Cooling Loops Result in Complicated Front-End Airflow



Data Credit: www.gm-volt.com

Relevance – VTM Objectives

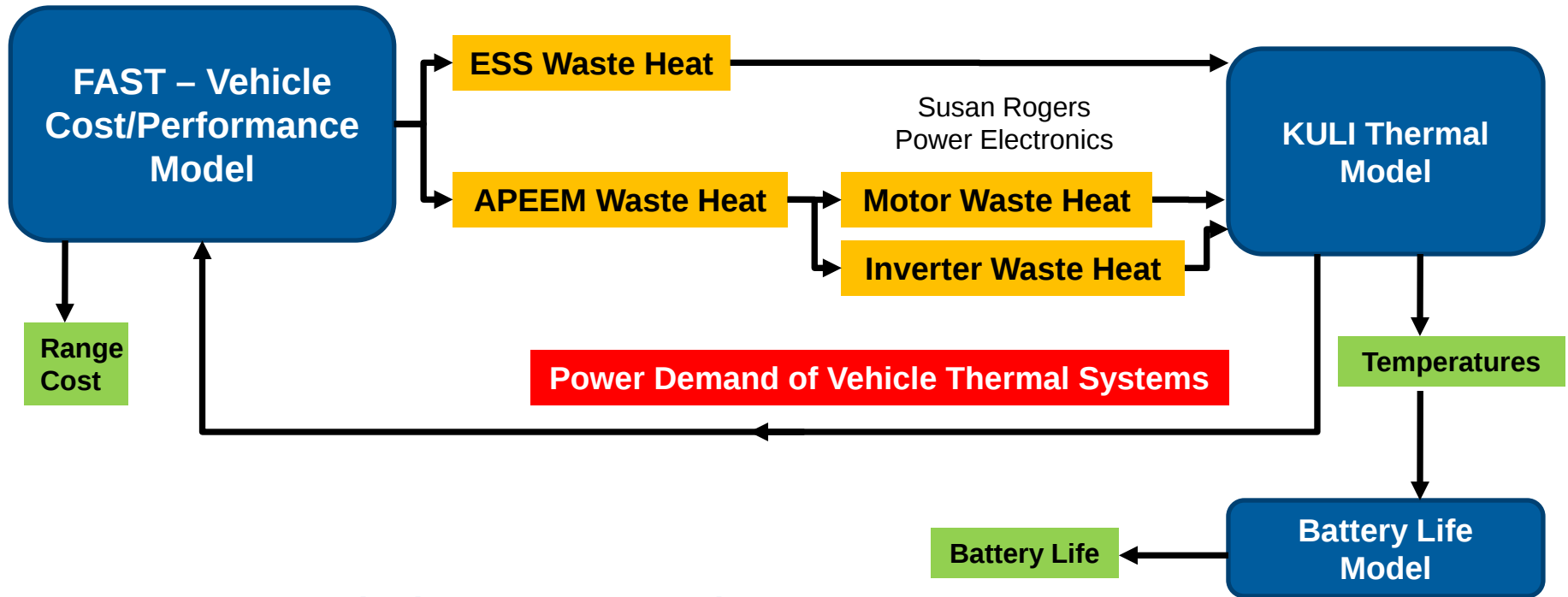
- Overall Objectives
 - Work with industry partners to research the synergistic benefits of combining thermal management systems in vehicles with electric powertrains
 - Improve PHEV and EV performance (reduced weight, aero drag, and parasitic loads)
 - Reduce cost and volume
 - Improve battery life
- FY11 Objectives
 - Develop a 1-D (lumped mass, uniform flow) thermal model using commercial software to assess the benefits of integrated vehicle thermal management and identify research opportunities

Approach

- Build a 1-D model (using KULI software) of the APEEM, energy storage, engine, transmission, and passenger compartment thermal management systems
- Combine with vehicle performance/cost and battery life models
- Identify the synergistic benefits from combining cooling systems
- Select the most promising combined thermal management system concepts and perform a detailed performance assessment with production-feasible component data
- Assess technical feasibility
 - Vehicle performance impact
 - Battery life impact
- Acquire additional OEM and supplier partners

Approach – Analysis Flow Chart

Lee Slezak, David Anderson
Vehicle Systems



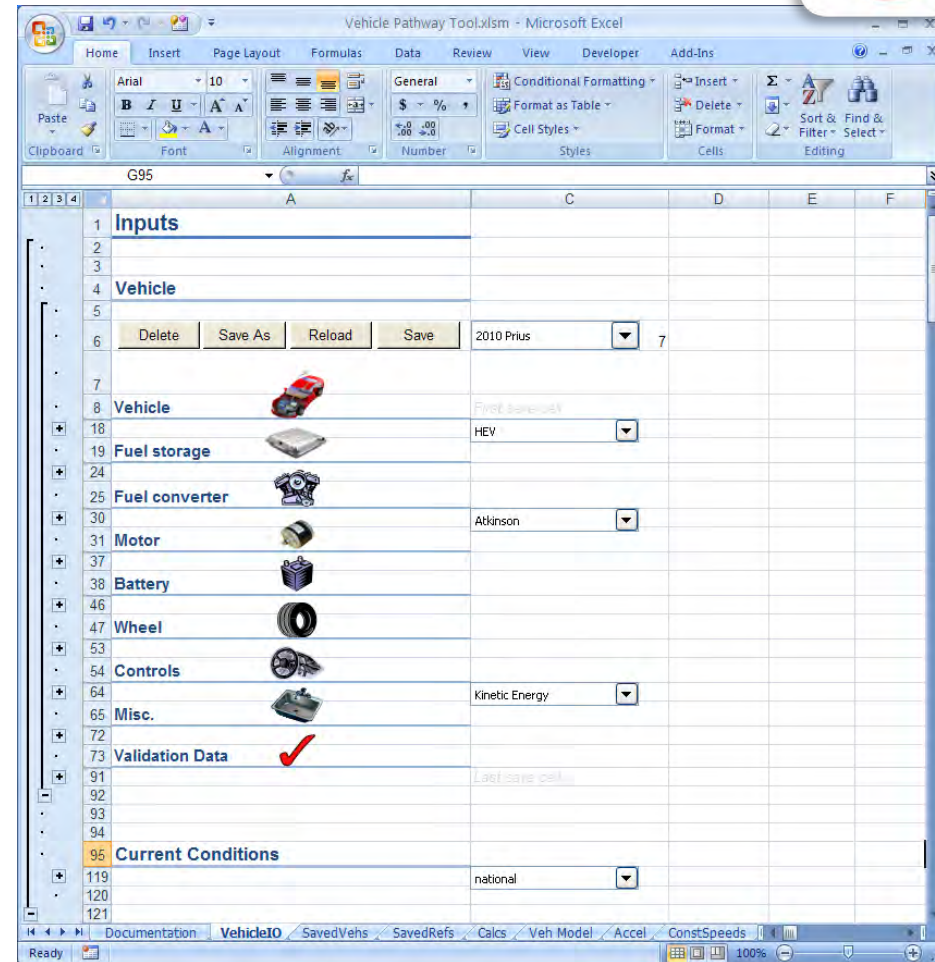
- Leverage existing DOE projects
 - Vehicle cost/performance model
 - Lumped parameter motor thermal model
 - Battery life model

FAST = Future Automotive Systems Tool

Approach – Future Automotive Systems Tool

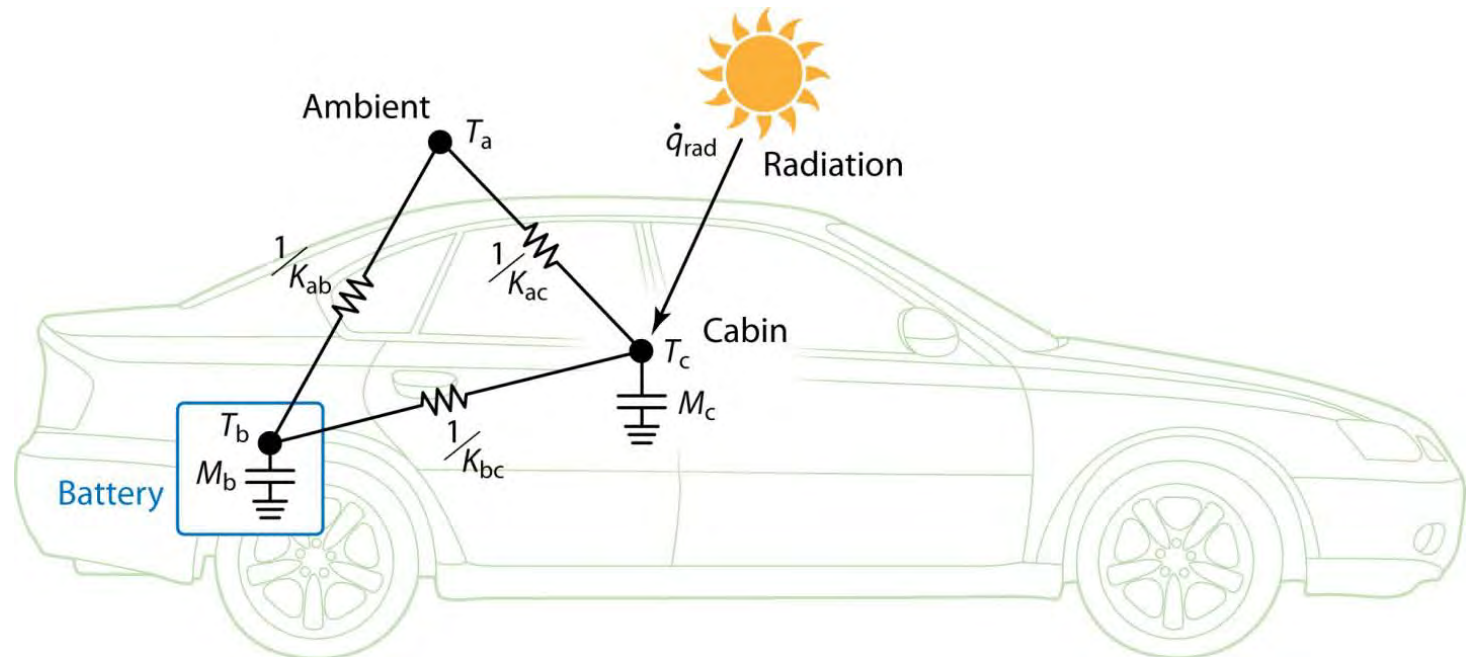


- Simplified vehicle simulation plus cost and battery life
- Approach: Include most critical parameters
 - Powertrain components (engine, electric motor, battery)
 - Auxiliary loads
 - Regenerative braking
 - Speed vs. time simulation
 - Battery life estimates
 - Cost estimates
- Application to vehicle thermal management project
 - Calculate heat generation
 - Assess impact of combined cooling loop strategies on vehicle range while maintaining equivalent cost



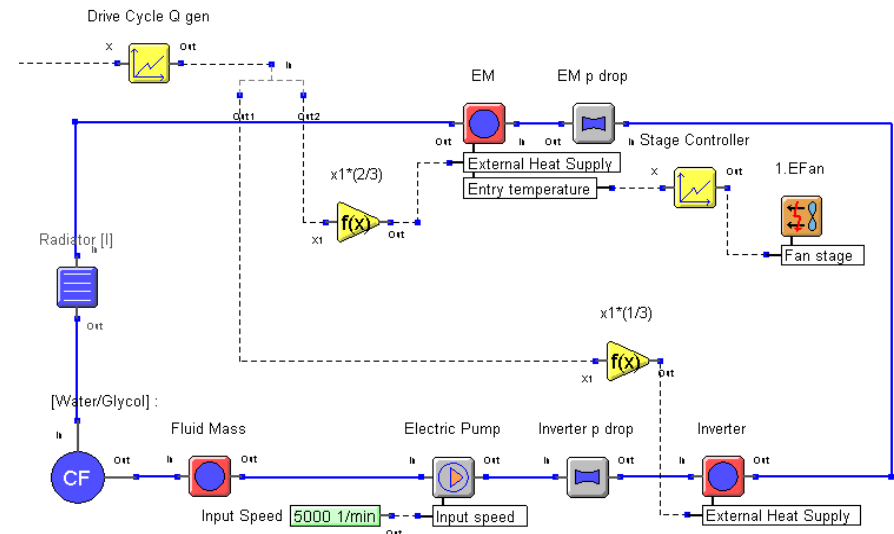
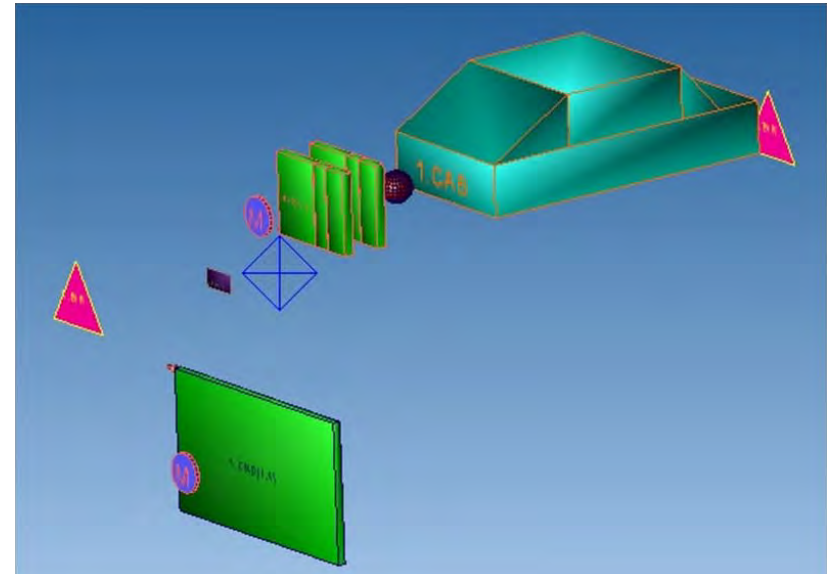
Approach – Battery Life Model

- Assesses the impact of temperature on battery life
- Accounts for degradation due to
 - Resistance growth
 - Capacity fade
- Includes life prediction using real-world Li-ion test data



Approach – KULI Thermal Model

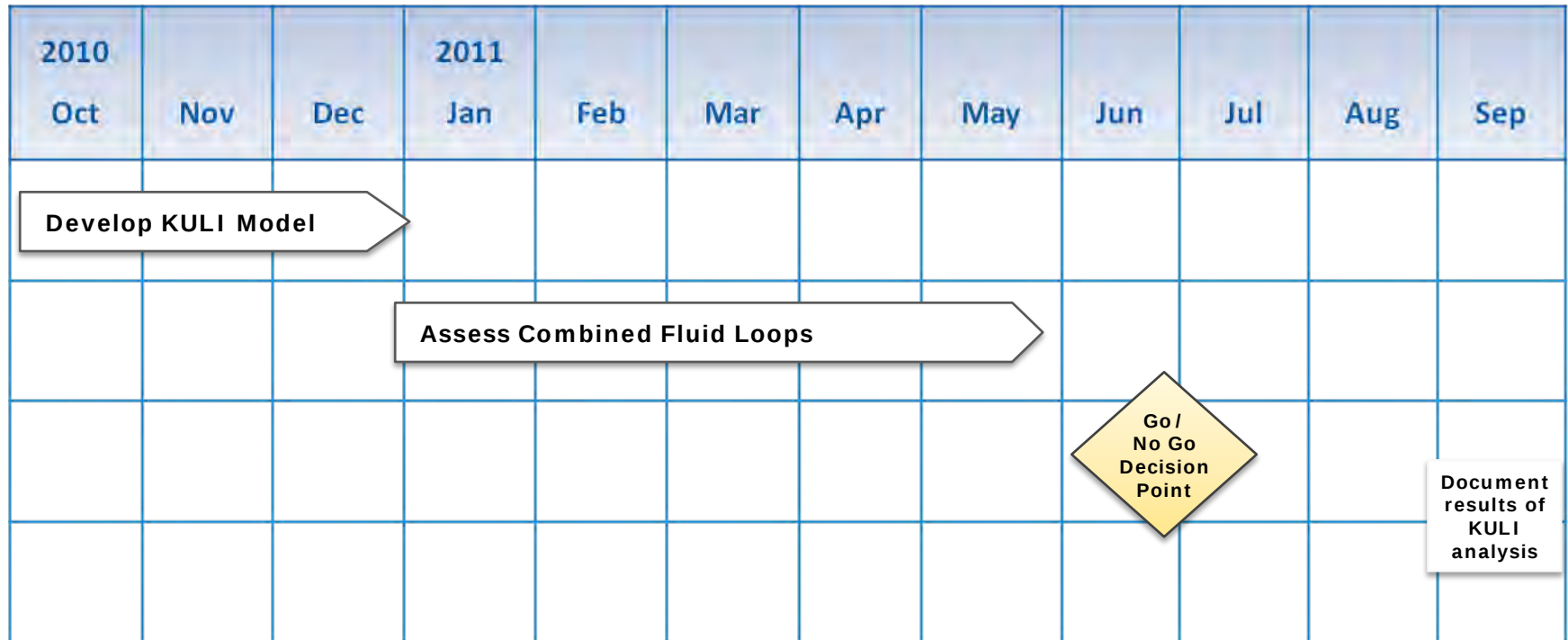
- 1-D thermal/fluid models using automotive industry commercial software package (KULI)
- Incorporate multiple vehicle cooling systems
 - Heating and cooling (HVAC)
 - Passenger compartment
 - Energy storage
 - Engine
 - Power electronics
 - Electric machines
 - Transmission



Approach – continued

- Address Targets
 - Improved range at equivalent cost from combining thermal management systems
 - Reduce the APEEM coolant loop temperature without requiring a dedicated system
 - Reduced volume and weight
- Uniqueness
 - Combining APEEM, energy storage, engine, and passenger compartment thermal management systems

Approach – Go/No Go Decisions and Milestones



Accomplishment – Built A/C Component Models

- High quality detailed component data
 - Provided by Visteon (Tier 1 HVAC component supplier)
- Built component models in KULI

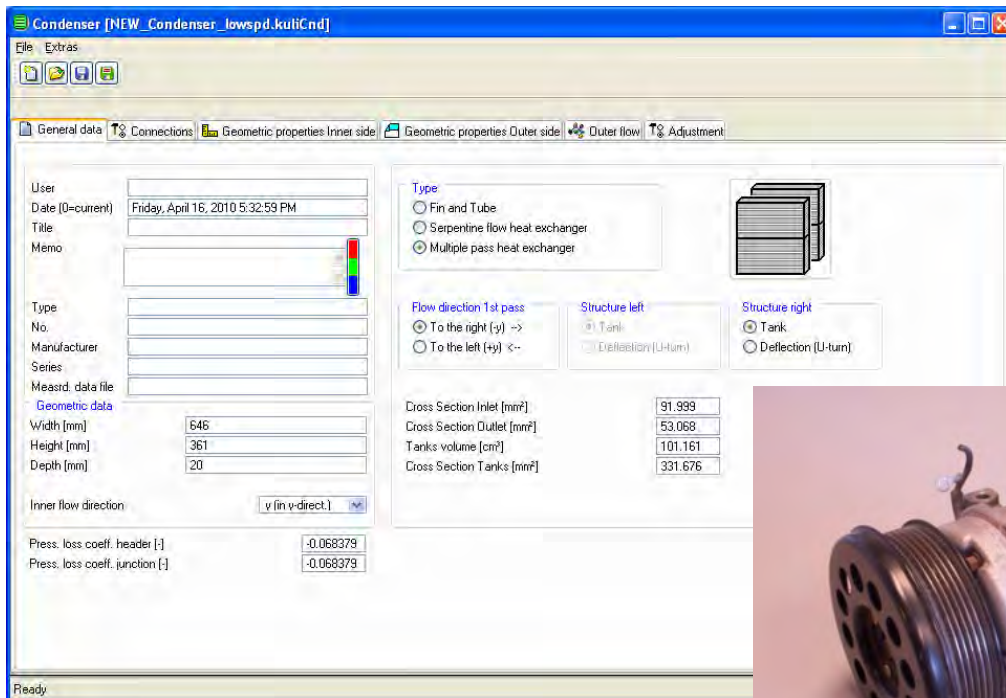
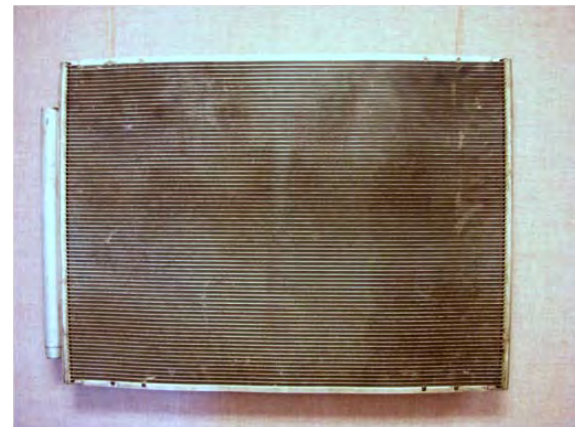
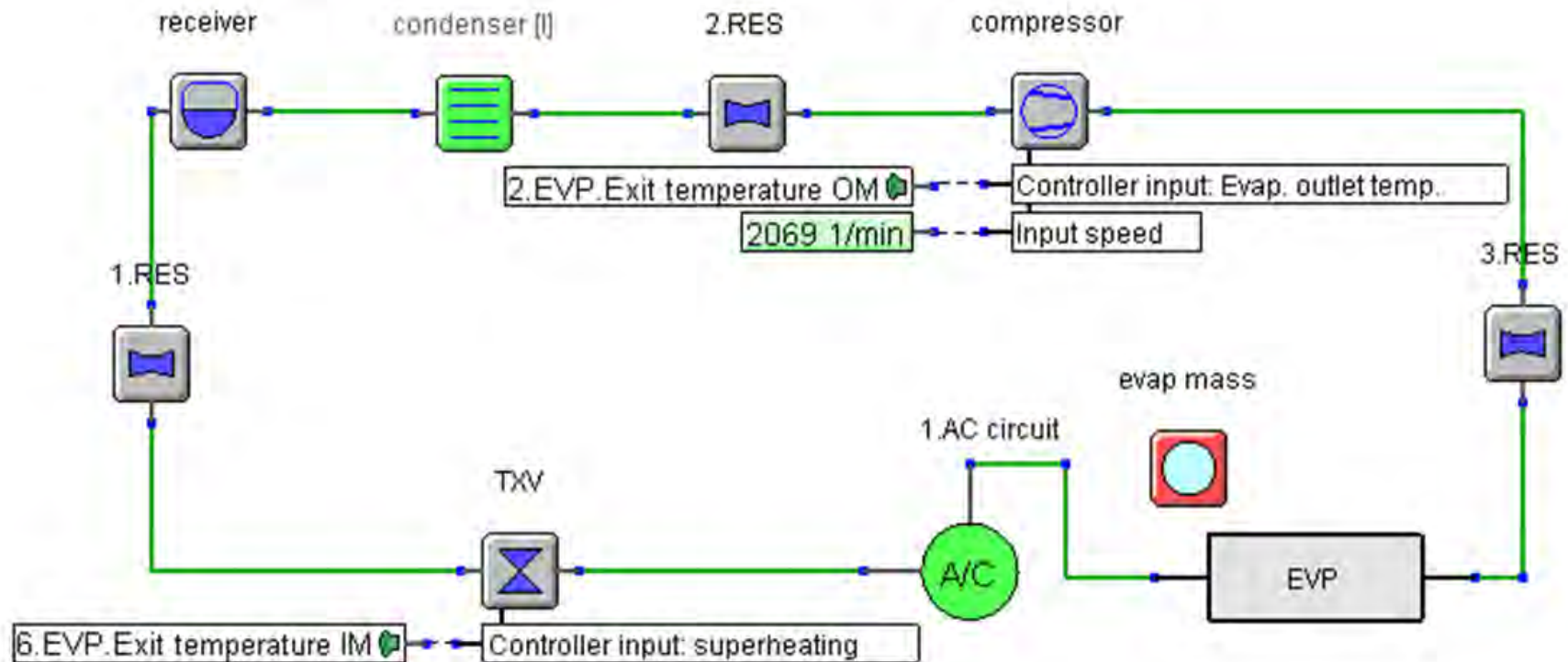
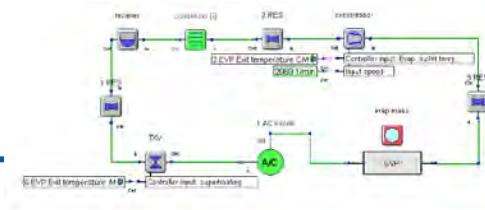


Photo Credits: John Rugh, NREL

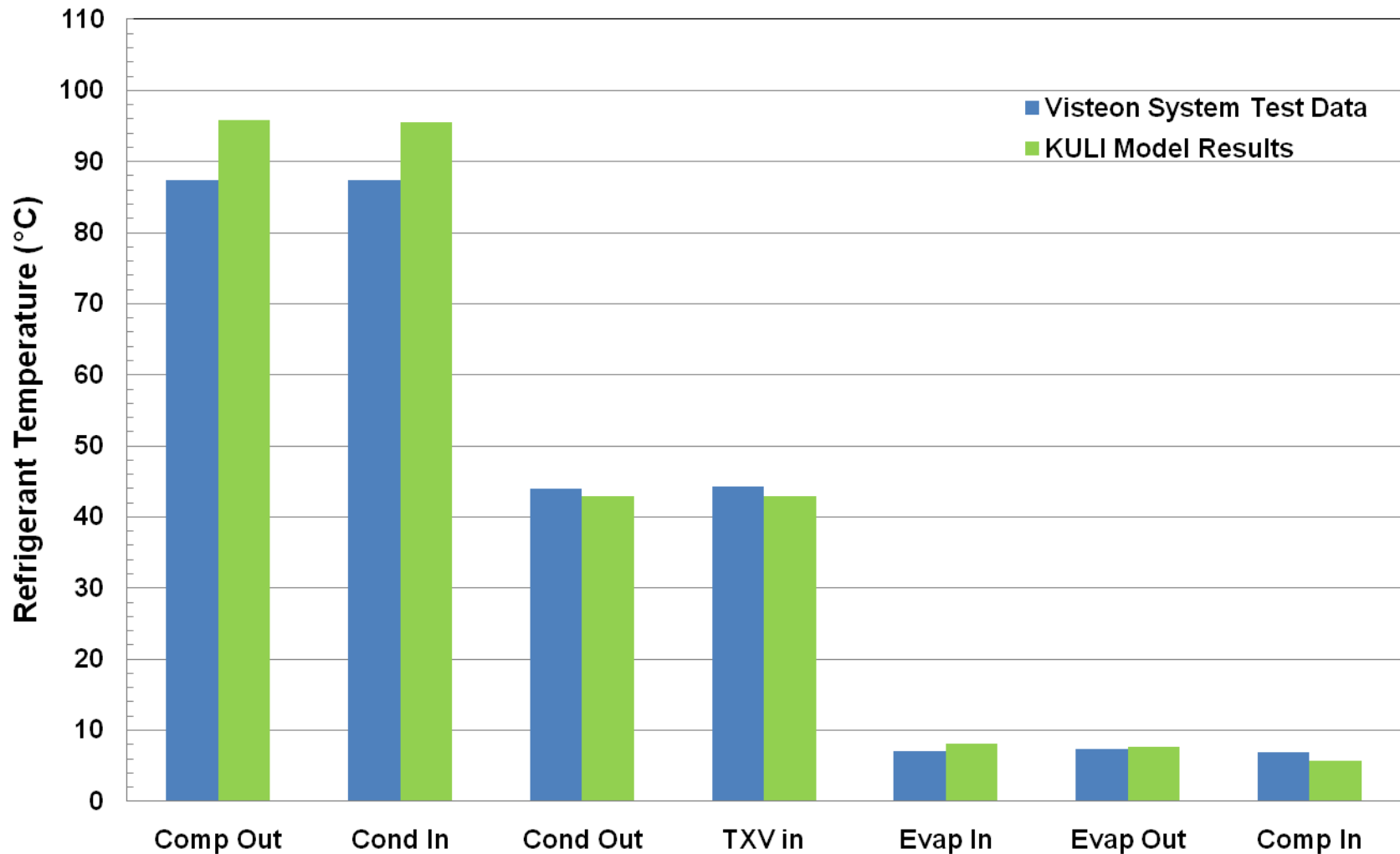
Accomplishment – Built A/C System Model



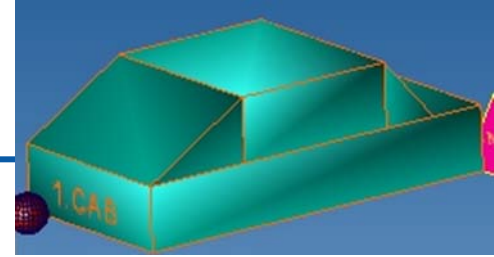
Accomplishment – A/C Model (cont.)



- A/C model results compared well to Visteon test data

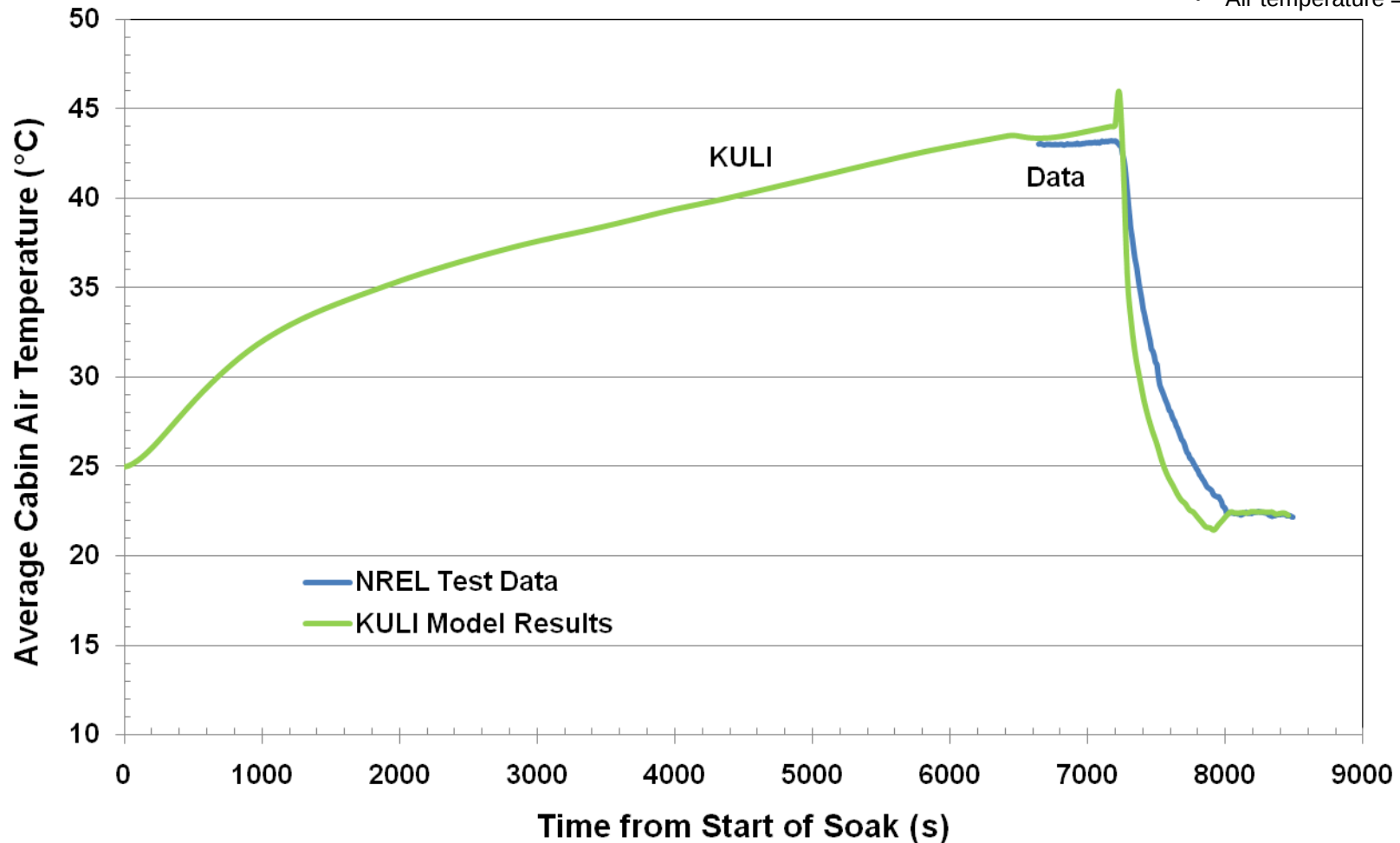


Accomplishment – Built Cabin Model



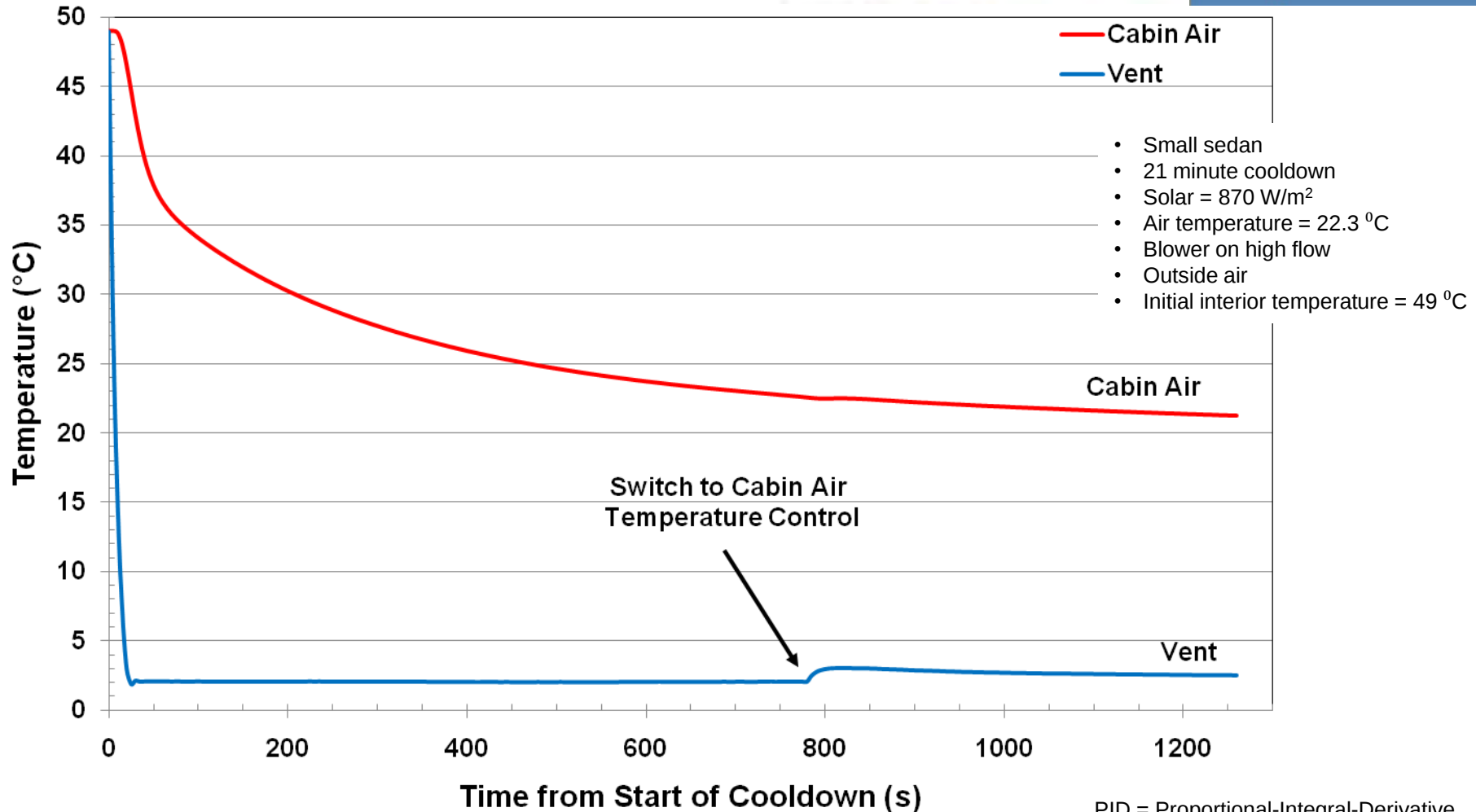
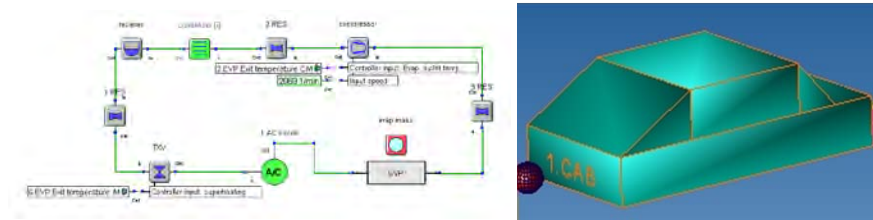
- Cabin soak and cooldown model results compared well to NREL test data

- Small sedan
- 2 hr soak, 21 minute cooldown
- Solar = 870 W/m^2
- Air temperature = 22.3°C

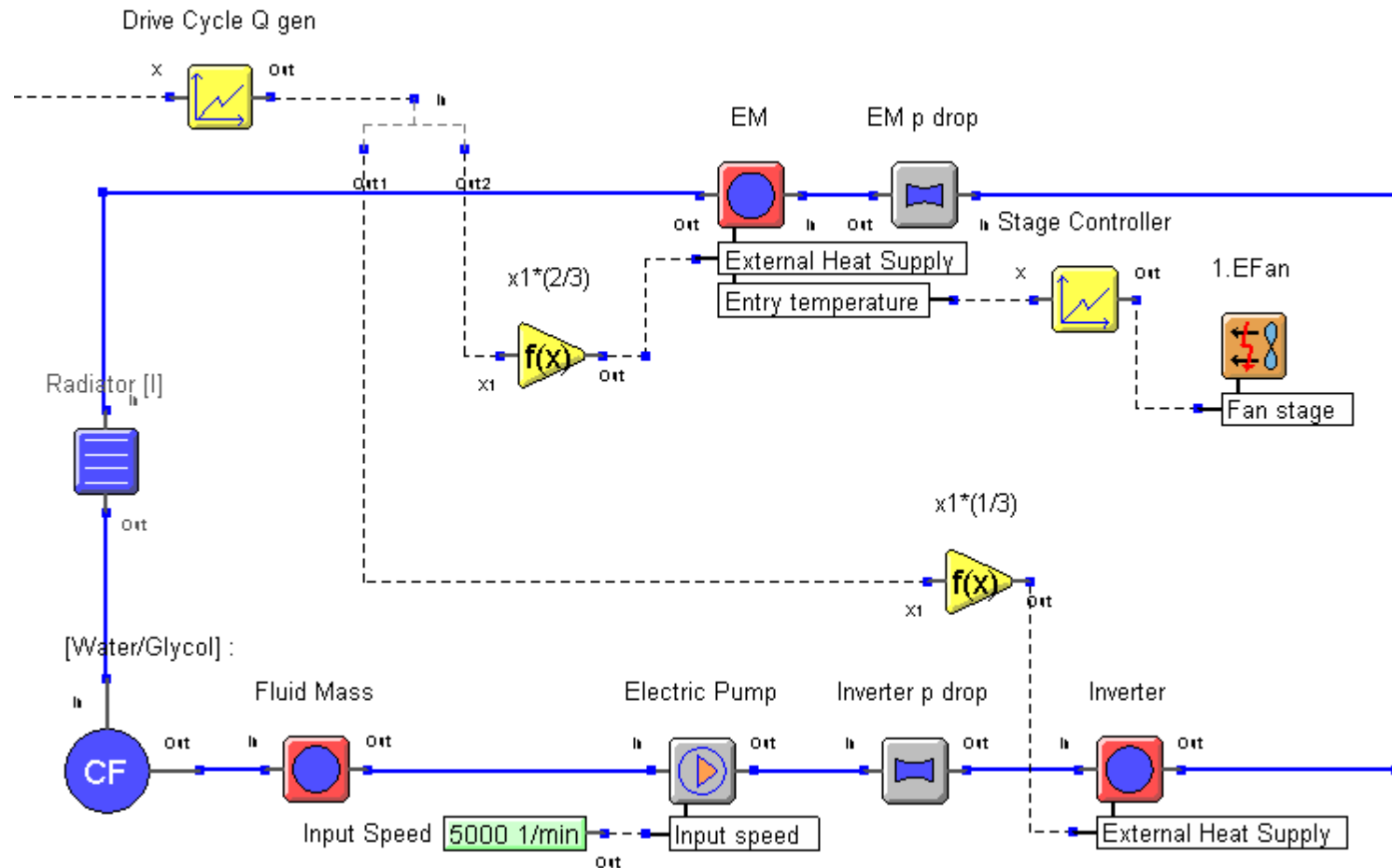


Accomplishment – Combined A/C and Cabin Models with PID Control

- Cooldown simulation demonstrates
 - Reasonable cooldown
 - Robust control

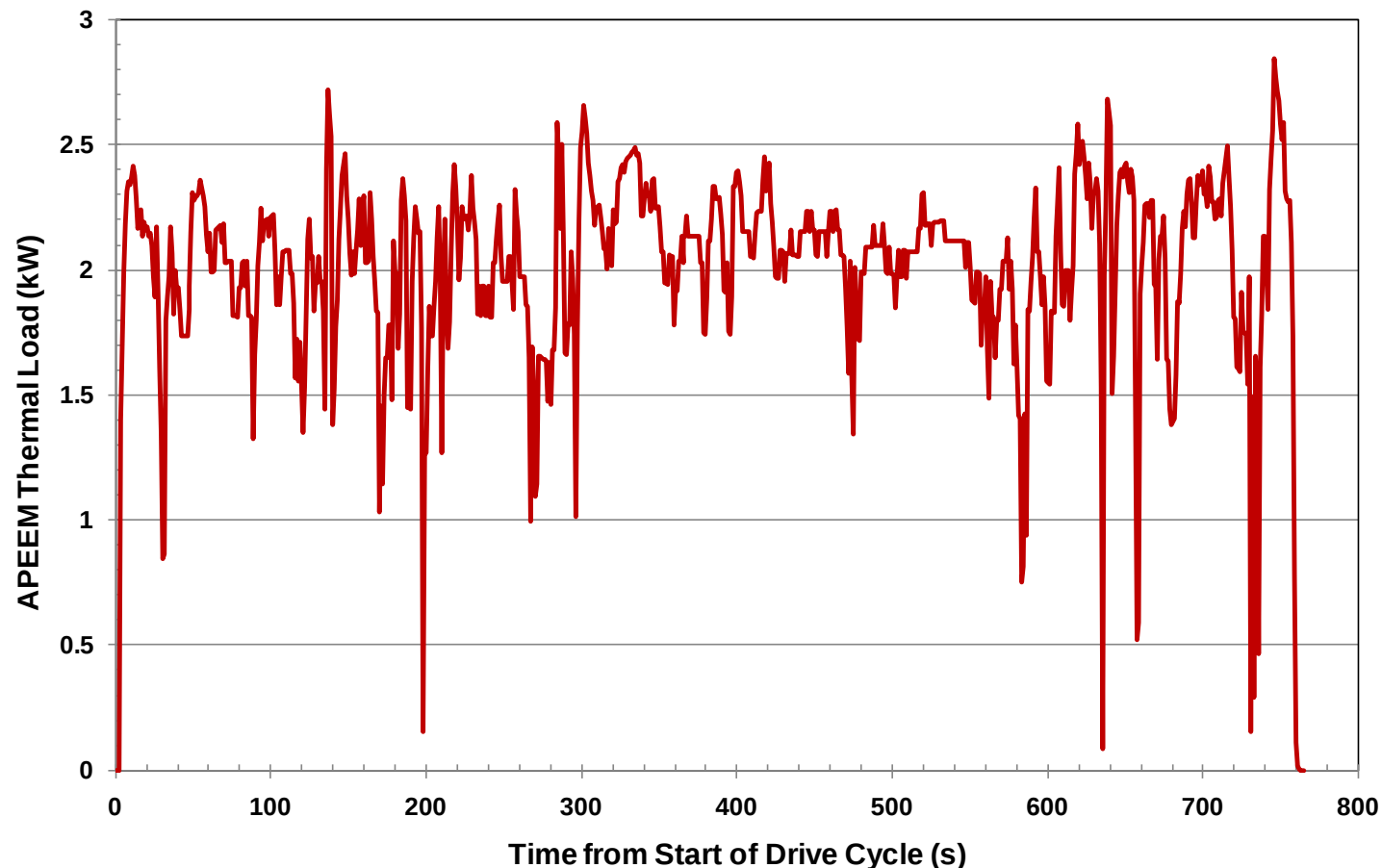


Accomplishment – Built APEEM Cooling Loop Model



Accomplishment – Heat Generation in the APEEM Components Input into APEEM Model

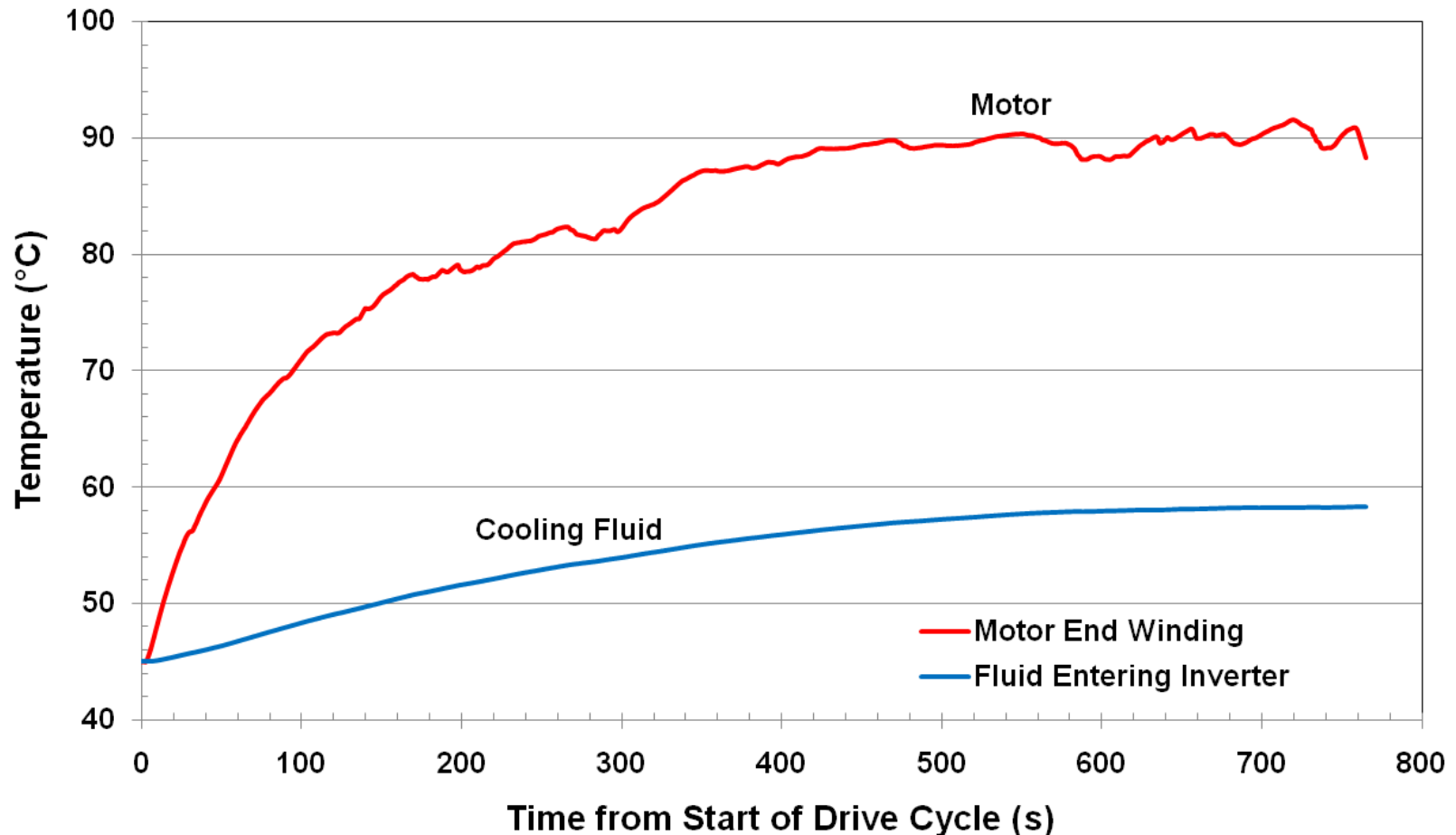
- Vehicle performance model output
- Nissan Leaf
- Drive Cycle: EPA Highway Fuel Economy Test



Accomplishment – APEEM Cooling Loop Model

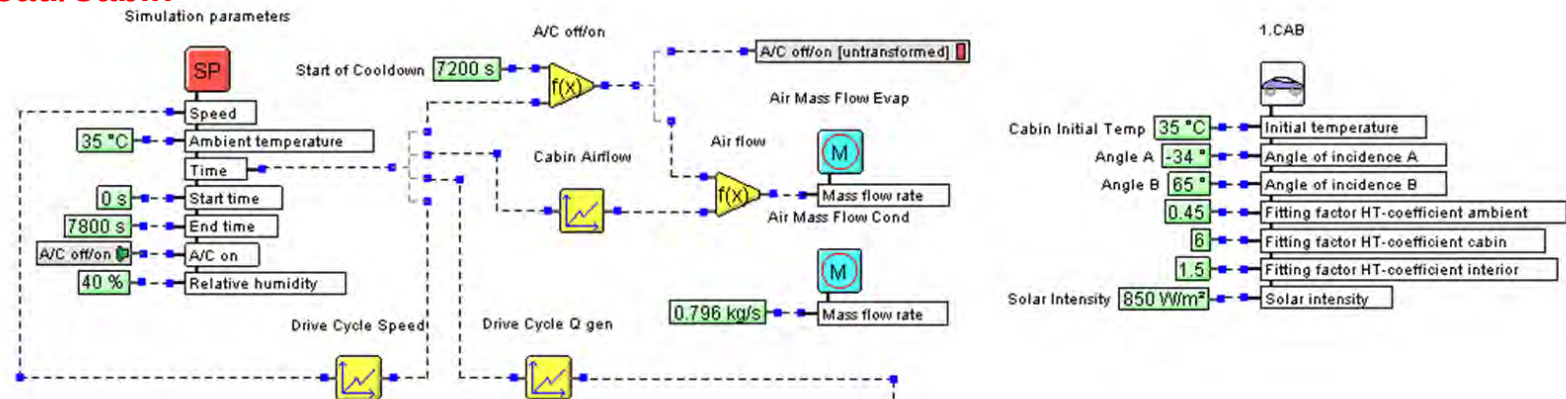
Produced Reasonable Fluid and Motor Temperatures

- Air temperature = 45 °C
- 5 L/min
- 50/50 Water – Ethylene Glycol

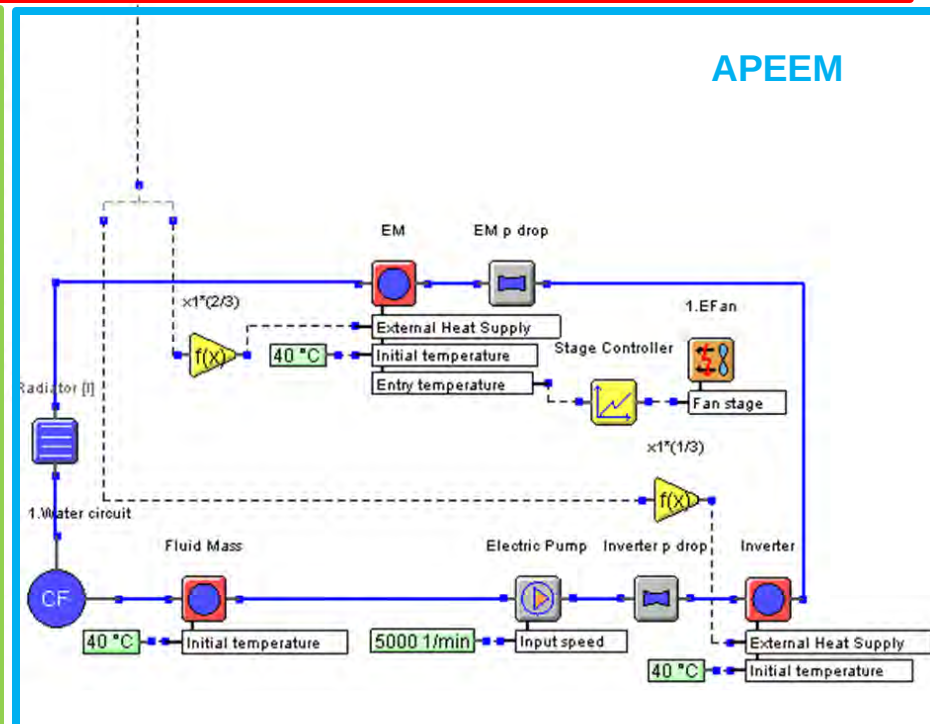


Accomplishment – Combined A/C, Cabin, and APEEM Cooling Loop

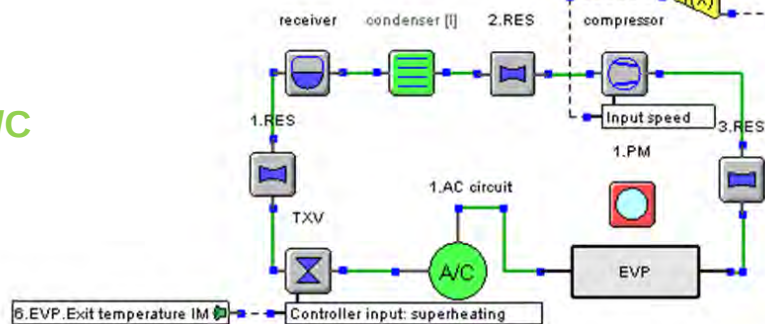
Heat Load/Cabin



APEEM



A/C



Collaboration

- Visteon
- EE Tech Team
- VTP Tasks
 - Vehicle Systems
 - Energy Storage
 - Advanced Power Electronics and Electric Motors

Future Work

- FY11 (March-September)
 - Build an ESS cooling loop model
 - Combine ESS model with A/C, cabin, and APEEM KULI models
 - Assess baseline thermal performance
 - Assess combined cooling loop strategies
- FY12
 - Based on the FY11 analysis, select, build, and evaluate a prototype system to demonstrate the benefits of an integrated thermal management system
 - Validate the KULI model with bench data and improve the model with updated component data as it becomes available
 - Engage automobile manufacturers and secure strong support from at least one OEM

Summary

- **DOE Mission Support**

- Combining cooling systems in EDVs may reduce costs and improve performance which would accelerate consumer acceptance, increase EDV usage, and reduce petroleum consumption

- **Approach**

- Build a 1-D model (using KULI software) of the APEEM, energy storage, engine, transmission, and passenger compartment thermal management systems
- Identify the synergistic benefits from combining the systems
- Select the most promising combined thermal management system concepts and perform a detailed performance assessment with production-feasible component data
- Solve vehicle-level heat transfer problems which will enable acceptance of vehicles with electric powertrains

Summary (cont.)

- **Technical Accomplishments**

- Developed a modeling process to assess synergistic benefits of combining cooling loops
- Built A/C and cabin KULI model
 - o A/C and cabin models individually validated
 - o Combined system produces reasonable cooldown
- Built APEEM KULI cooling loop model
 - o Produces typical component and fluid temperatures
- Ran performance model of a Nissan Leaf to provide APEEM heat generation

- **Collaborations**

- Collaborating closely with Visteon
- Leveraging previous DOE research
 - o Battery life model
 - o Vehicle cost/performance model
 - o Lumped parameter motor thermal model
- Co-funding by three VTP tasks demonstrates cross-cutting

Acknowledgements, Contacts, and Team Members

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Susan Rogers

Lee Slezak

Vehicle Technologies Program

EE Tech Team

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