DOE's Vehicle Technologies Office

Electric Drive Technologies, Grid, and Infrastructure

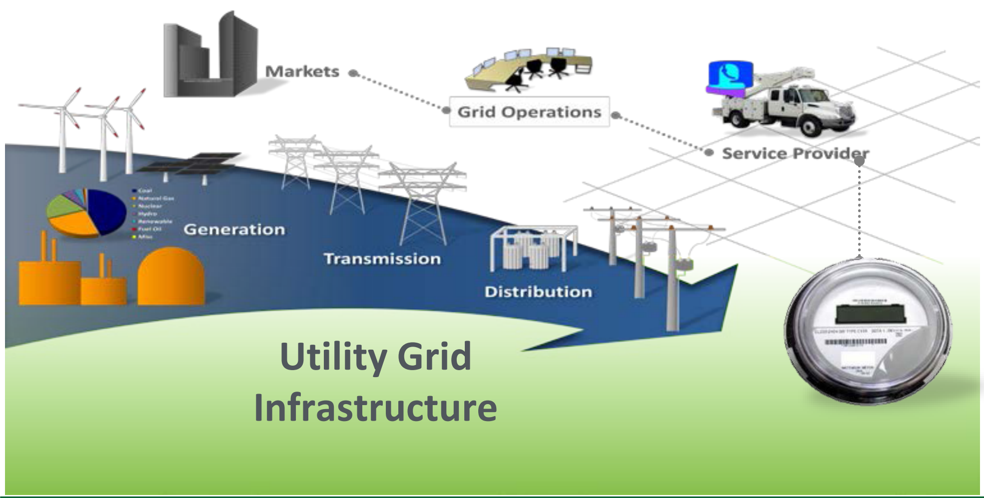
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

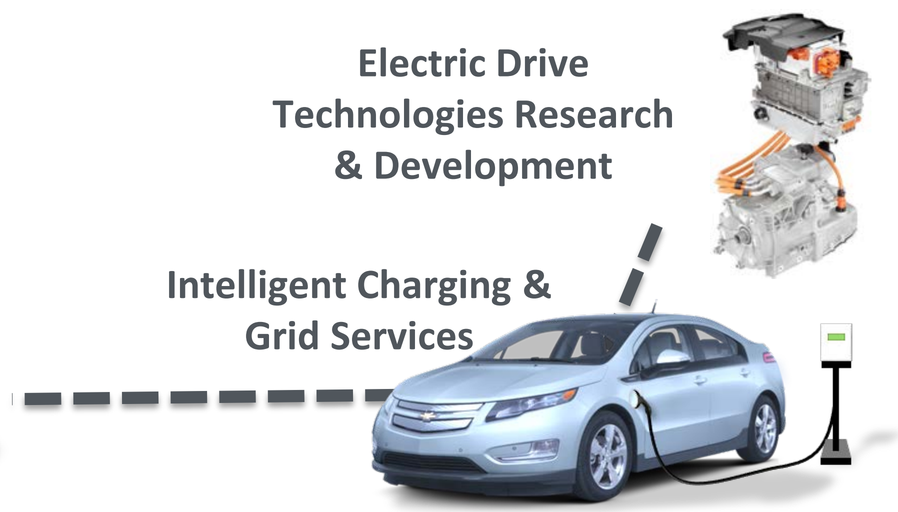
Steven Boyd
Technology Manager
Office of Energy Efficiency and Renewable Energy

EDT G&I Overview

Increase the benefits and reduce the barriers to vehicle electrification through R&D and related supporting opportunities

- Electric Drive Technologies (EDT): 100 kW Electric Drive System $6/kW in 2025
- Develop technologies that minimize the impacts of EV charging on the Nation's electric grid and support vehicle electrification
- There is significant continuing interest for vehicle electrification from the automotive industry





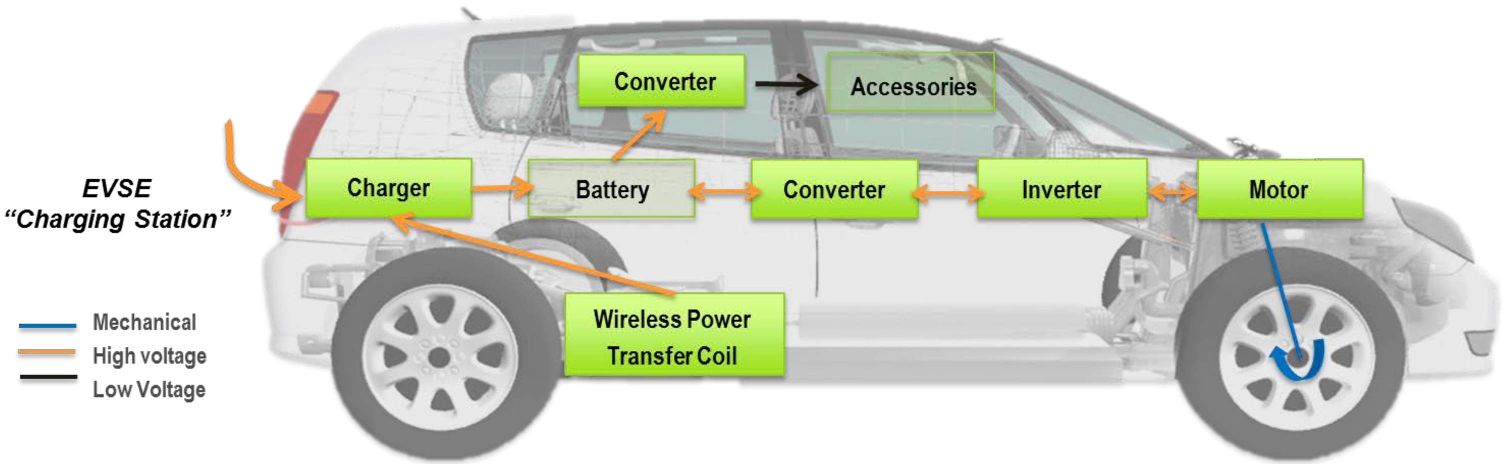
Electric Drive, Grid & Infrastructure Budget: Past & Present

Funding in millions	**FY 2016** Enacted	**FY 2017** Enacted
Electric Drive Technologies	$38.1	$19.3
Vehicle Systems	$30.6	$44.5
-Grid Modernization	$10.0	$9.5

VTO Electric Drive Technologies

Mission: Accelerate the adoption of electric drive technologies to enable a large market penetration of electrified vehicles

- **Program target focus**
  - Reduce system level costs to improve the total cost of ownership
  - Significantly increase power density to enable widespread applications
  - Double component life (300K miles) for new mobility services



2025 GOAL: Reduce the cost of electric drive system to $6/kW

(50% decrease from 2015 baseline)

Electric Drive Technology R&D

- **Fundamental shift is occurring in electrified vehicle architectures and applications**
  - EVs are moving to modular, skate board architectures
  - Larger vehicles are being electrified
  - Enabling fleet applications based on total cost of ownership
  - Faster, high power charging is essential

  Result: Higher vehicle voltages >600V

- **Issues**
  - Higher cost electric drives ➔ Low cost electric drive technologies
  - Higher power levels ➔ Significantly higher power level systems, with new technologies and designs are required
  - Space premium ➔ Cargo/passenger carrying capacity impact and PHEV packaging constraints

  Result: Higher power density designs are of utmost importance

Recent EDT Research Focus

Power Electronics

Highly integrated gate drivers, advanced packaging, thermal management, capacitors, and inductors enabling low cost and high power density inverters, converters, and on-board chargers

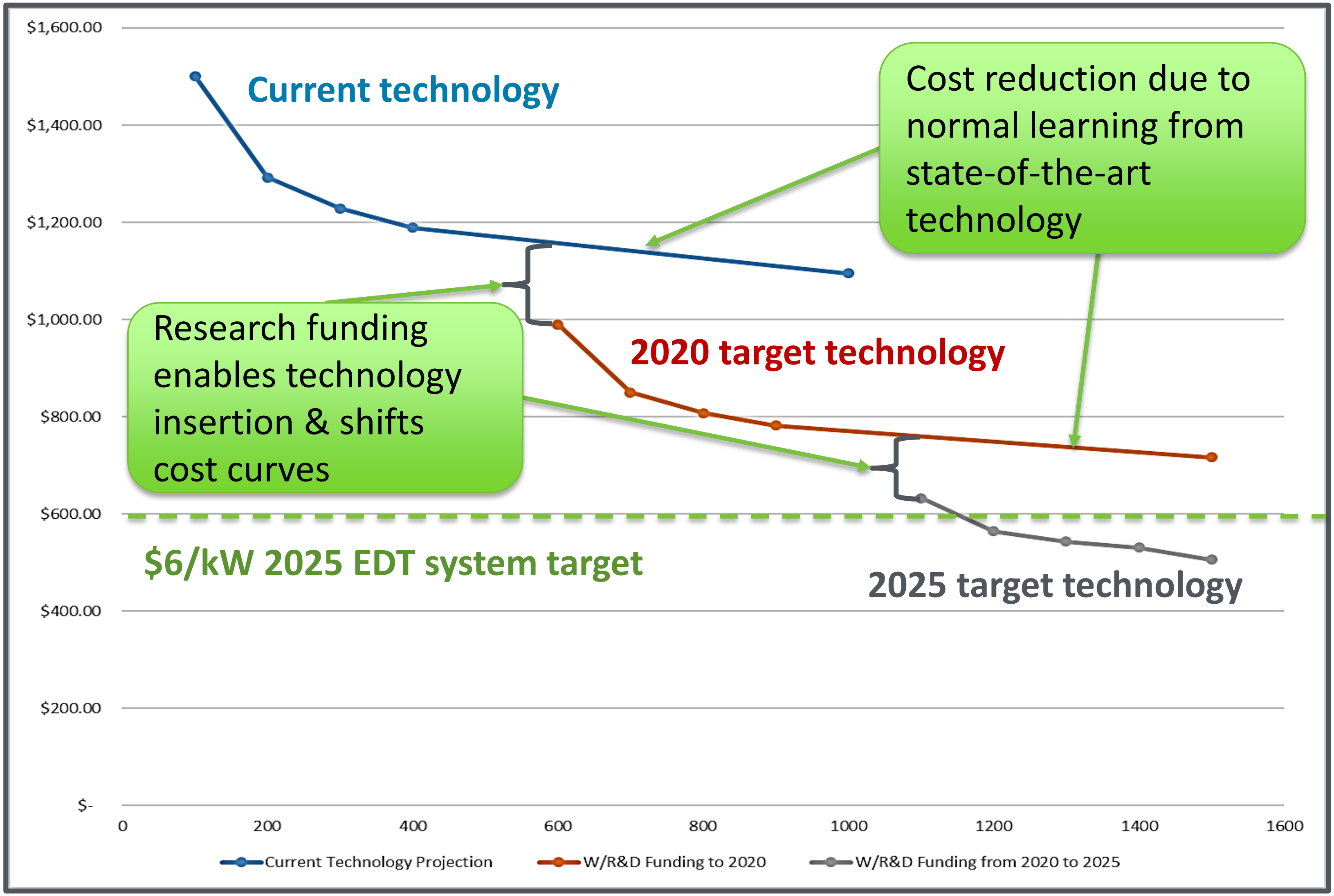
- High frequency switching capable power modules with low parasitic inductance (<10nH)
- Wireless charging integrated into the electric drive
- More integration of gate drivers, power semiconductors, and capacitors

Electric Motors

New copper, steel, and magnet materials and their application in motor designs for optimized performance

- Nanotube based ultra conducting copper that can increase conductivity of copper up to 30%
- Atoms to motors modeling of materials on supercomputers for better utilization of motor materials
- High performance computing for design optimization of electric motors

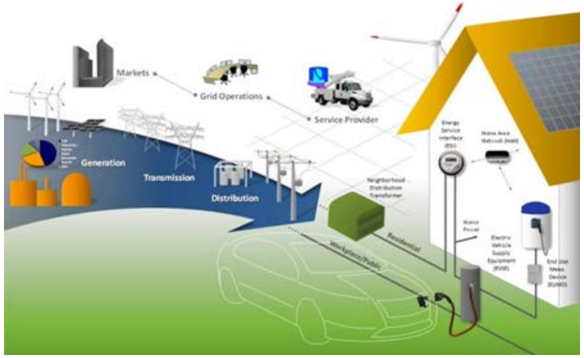
EDT Research Achieves Cost Targets



Note: 100 kW EDT system & 100,000 unit annual production volume

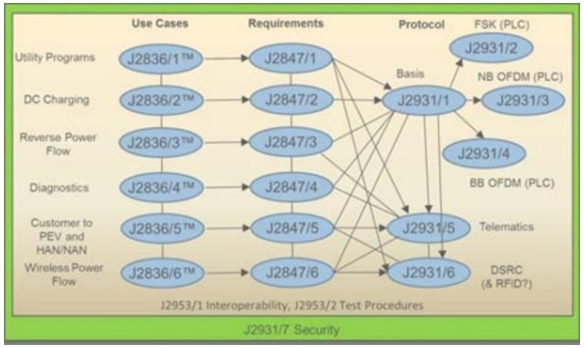
Grid and Infrastructure (GI) Overview

- Develop technologies that minimize the impacts of EV charging on the Nation's electric grid
  - Prototype communication and cybersecurity protocols
  - Improve interoperability of charging equipment, on-board vehicle charger, and charging networks
- Enhance EV refueling such as wireless power transfer (WPT) and high power charging (HPC)
  - 2018 focus on understanding cost and technical barriers of HPC grid and charging infrastructure capable of charging an EV battery in 15 minute or less
  - HPC will provide 350+ KW power (3X improvement)



GI Overview: Transportation Electrification

- **<u>Codes & Standards</u>** supports timely development and adoption for grid connected vehicles
  - Communications, Connectivity, Charging
  - National Labs – ANL, PNNL, INL, LBNL
  - EV Smart Grid Interoperability center supports international harmonization



- **<u>Zero Emission Cargo Transport</u>** (ZECT)
  - Focus on grid connected MD HD package delivery applications
  - HGAC - EV MD Delivery & H2 Drayage
  - SCAQMD -EV & PHEV Drayage trucks
  - Cummins – PHEV MD Delivery
  - McLaren – PHEV MD Delivery
  - Bosch – PHEV MD Delivery

USHybrid BET

GI-Overview: Transportation Electrification

- **GMLC** supports intelligent integration of EVs into the grid
    - Four foundational projects
        - Control Theory, Testing Network, Grid Services, New York State Energy Initiative
    - Four vehicle specific projects focus on
        - Grid and building services from connected vehicles at building distribution and national levels
        - Cyber security
    - Two industry awards
        - EPRI, CALSTART
- **High power charging** infrastructure
    - Intertek charging studies address back compatibility and grid impacts.
    - ANL acquiring prototype hardware for evaluation

VTO Charging R&D – Reducing Time

Current Availability				
	Level 1	Level 2	DC Fast Chargers	
			50kW	140kW
Examples of Charging Stations				
Electrical Current Type	AC	AC	DC	DC
Range per Charge Time	2-5 miles/ 60 minutes	10-20 miles/ 60 minutes	50-70 miles/ 20 minutes	170 miles/ 30 minutes
Vehicle Charge Ports	J1772 	J1772 	J1772 combo  CHAdeMo 	Tesla combo 

Future Availability

Extreme Fast Charging – up to 350kW

~15 mins to charge for 200 miles

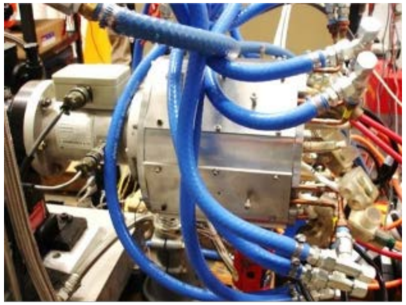
Provides significantly faster charge rates than anything else on the market

EDT Research Highlights

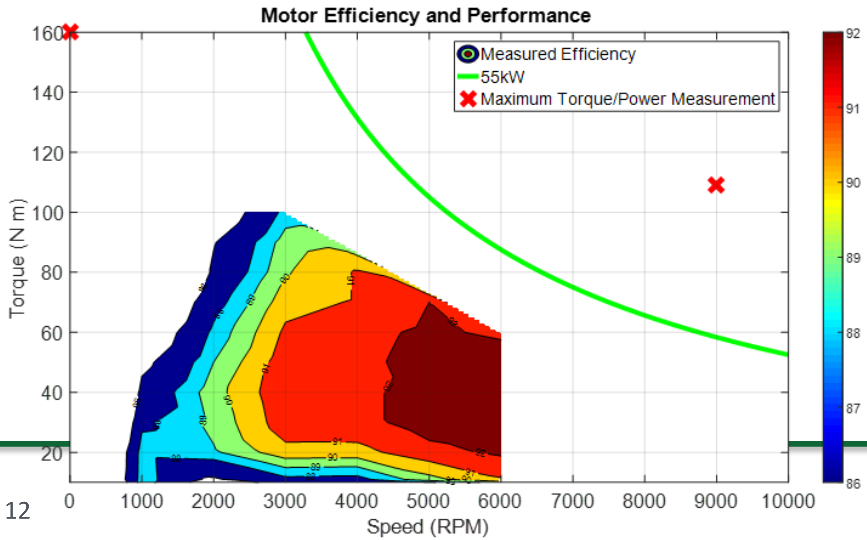
High Power Density Ferrite PM Motor

Non-rare earth motors are critical to achieving low-cost high power density electric traction drives

- Achieved >103 kW peak power with a proof-of-principle low-cost motor that has same volume as 60 kW motor in 2015 Prius
- Meets DOE 2020 cost and power targets



ORNL ferrite motor prototype on dynamometer



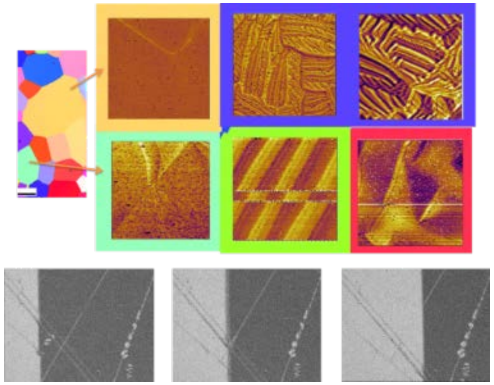
Supercomputers Improve Magnetic Materials

A unique simulation tool based on scaling laws and high performance computing for capturing domain formation and evolution under external magnetic fields

- Developed advanced modeling tool
  - Stress distribution
  - Advanced FEA modeling
  - Bulk characterization
  - Localized magnetic properties
  - Empirical magnetic domain analysis
  - Theoretical magnetic domain analysis
- Awarded 2.25 million core hours on supercomputer
- Performed 2D FEA code successfully

Empirical magnetic domain analysis

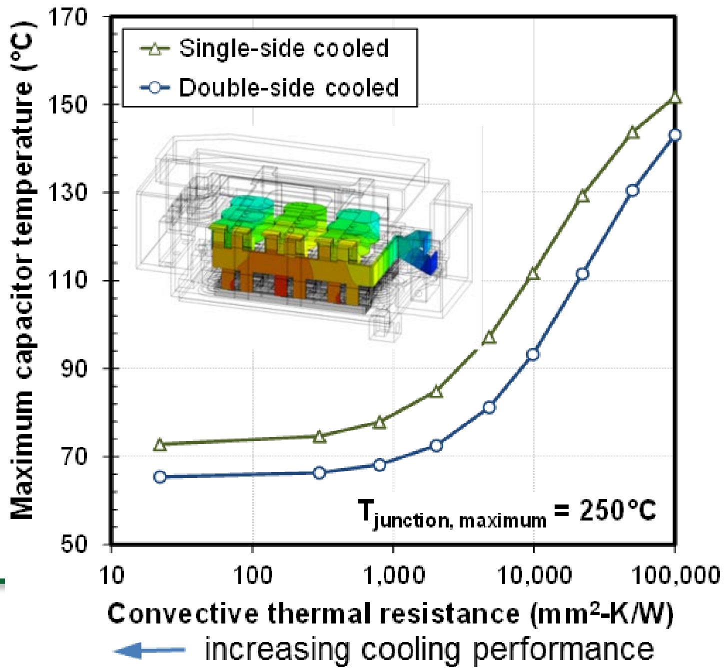
- Traditional Epstein and ring specimen testing
- Impacts of stress, pinning, etc. upon domain wall movement, and ultimately magnetization/loss properties



EDT Research Highlights

Enabling Power Dense, High Temperature Systems

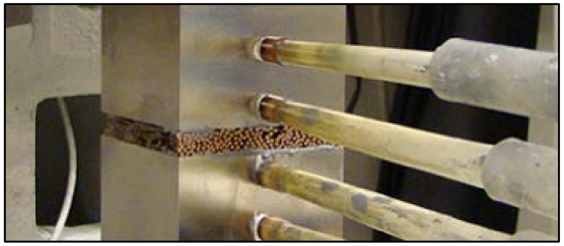
- Capacitors, electrical boards, and module interface layers exceeded their allowable operating temperature limits in WBG designs
- Cooling the electrical interconnections is more effective than directly cooling the capacitors
- Electrical interconnect (figure below) cooling approach enables capacitors to operate within allowable temperature limits at WBG junction temperatures up to 250°C



Thermal Materials Innovations for High Performance Motors

- Anisotropic thermal conductivity of packed copper wire can be estimated using laser flash and transmittance measurement methods (table below)
- Provide a baseline for new materials and structures for motor windings

Measurement Approach	Parallel to Wire Axis	Perpendicular to Wire Axis
Laser Flash E1461	Yes	Yes
Transient Plane Source ISO 22007-2	No	No
Thermal Transmittance ASTM D5470	No	Yes



Thermal transmittance setup for thermal measurements perpendicular to the wire axis

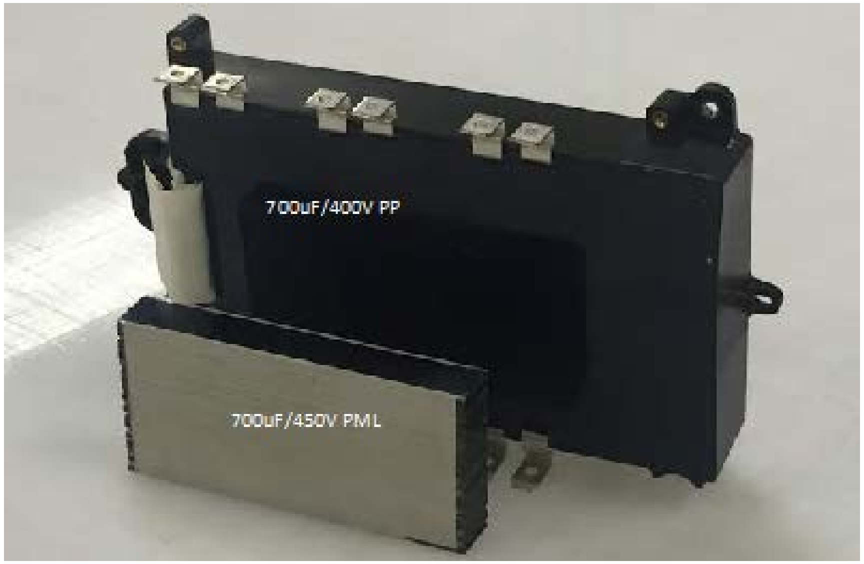
EDT Development Highlights

Sigma Technologies PML high-temperature DC bus capacitors

- Solid-state Polymer-Multi-Layer (PML) production process represents a potentially transformational development for DC bus capacitors
- Large, full scale prototype capacitors have been produced and tested for durability and in a representative inverter with partner Delphi
- Sigma is in the process of designing and fabricating a production scale machine to manufacture bulk PML capacitor material
- Parts have already reached applications – currently used in Formula-e race cars

Characteristic	DOE Target	PML Capacitor
Temperature	-40 to 140°C	-40 to 140°C
Loss	1 %	< 1 %
Volume	< 0.6 L	< 0.3 L
Cost	< $30	< $20

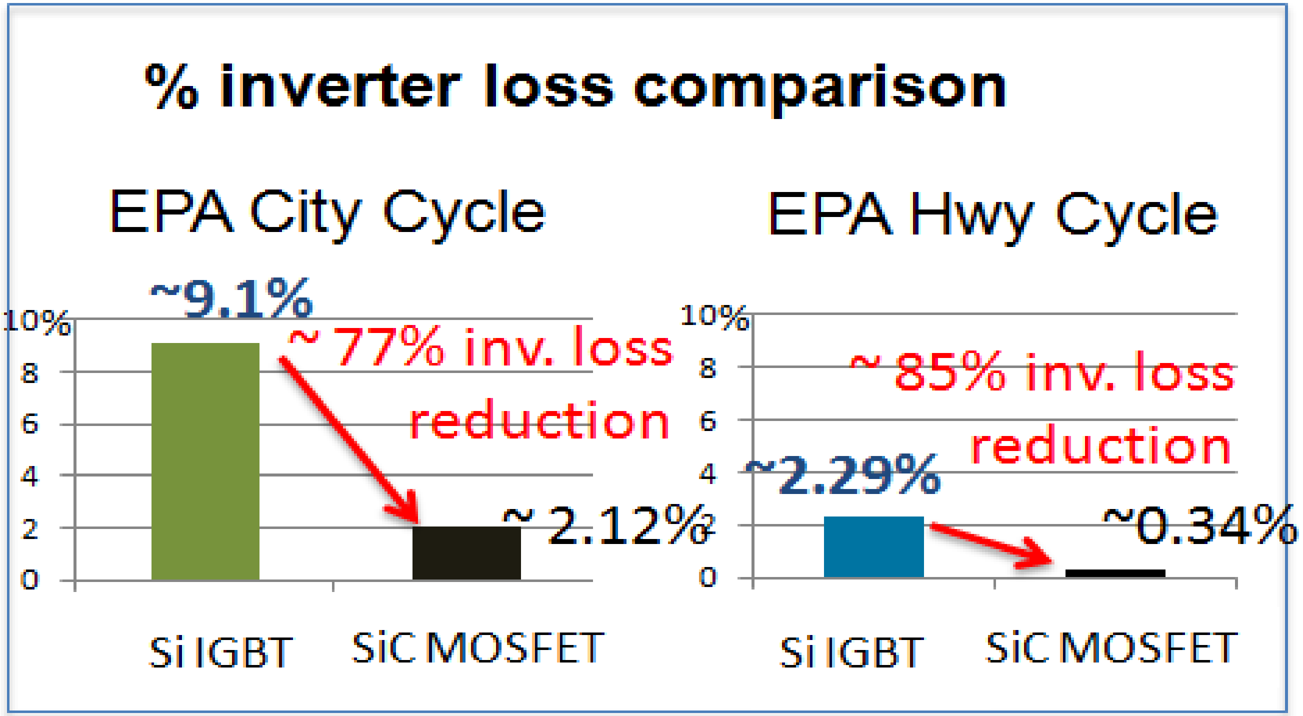
Sigma PML capacitor performance compared to DOE capacitor development targets for a ~700 µF capacitor.



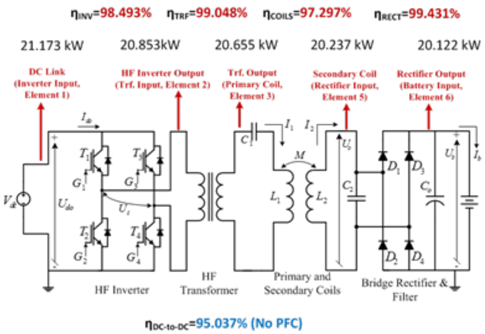
EDT Development Highlights

Wolfspeed SiC devices for low-loss electric drive systems

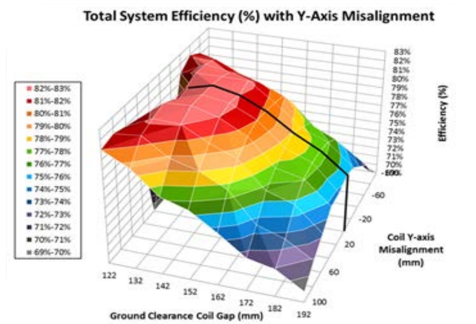
- Overall semiconductor area is a significant driver for device cost, and these SiC devices are about 1/3 smaller than comparable silicon-based devices
- Additional high temperature capabilities of SiC can enable other beneficial drive system benefits or characteristics, such as cooling requirements and power density
- These devices can enable a reduction in inverter losses up to 85%, from about 7% of overall EV losses to 2%
- Collaboration with 9 automotive OEMs, 3 Tier One and 1 Tier Two automotive suppliers



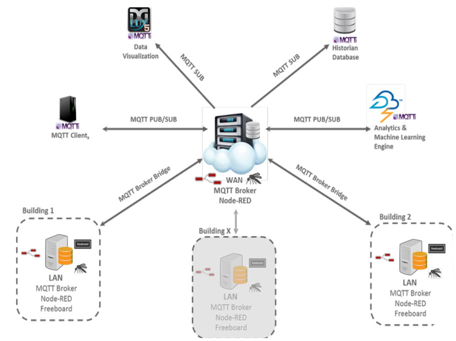
Grid Integration Accomplishments



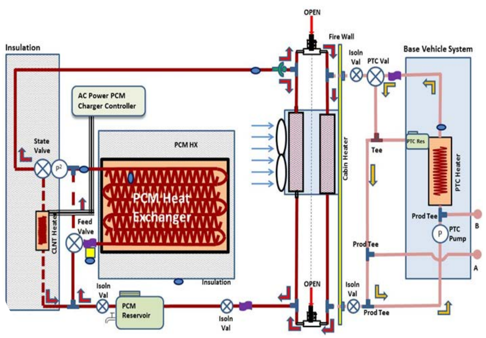
ORNL demonstrated 20KW WPT at 90% efficiency



INL advanced WPT Interoperability testing



EVs join IOT at ANL Smart Energy Plaza



Mahle integrated ePATHS into Ford Focus Electric

NREL evaluated thermal load reduction technologies for a 2016 PHEV

EV Sub-metering technology transitioned to commercial building application

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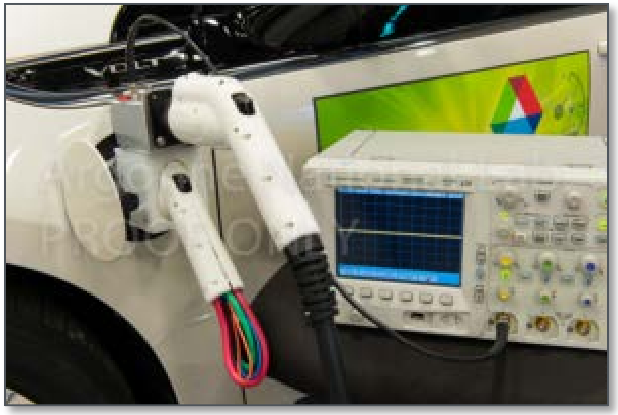
EV GI at the Energy System Integration Facility

- PEV Integration with Renewables (INTEGRATE Project)
    - interplay of vehicle charge management with local and bulk renewables; data stream integration
    - Device characterization, communications and controls layer evaluation and development, market assessment and demonstration
- Focused projects
  – V2G Scenario Development, Modeling, and Tech Transfer
  – V2G Tech. Standards and Policies Development
  – EVGI Technology Development Partnerships and Demonstrations

EV Smart Grid Interoperability Center

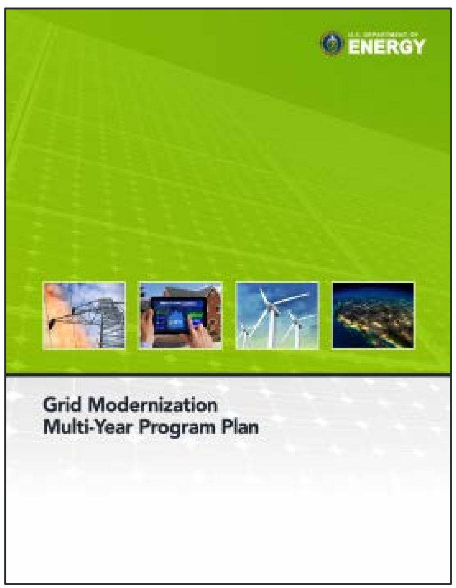
- **Interoperability Center**
  - Developed SAE J2953 Interoperability standard, compliance tools, procedures
  - Developed and licensed SpEC module for EV-EVSE-grid communication
  - Established centers at Argonne and EC's Joint Research Center; Agreement with
  - China; in process with Taiwan, APEC
- **Charging and V2G Technology R&D**
  - AC/DC charging (communication R&D)
  - Workplace charging (integrated metering, communication and control)
  - Reverse power flow (off-board inverter).
- **Metrology Application Engineering**
  - End-Use Measurement Device (EUMD) and sensor application engineering. Metering technology development and implementation in support of NIST HB44 and grid integration.



EDT G&I Partnerships

- U.S. DRIVE Tech Teams: Electrical and Electronics, Grid Interaction, and Vehicle Systems Analysis
- DOE: Power America, Critical Materials Institute, and Grid Modernization

USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY



POWERAMERICA

CMI
Critical Materials Institute
AN ENERGY INNOVATION HUB

EDT G&I Road Maps/Major Reports

- FY 2015 Advanced Power Electronics and Electric Motors Annual Progress Report: http://energy.gov/eere/vehicles/downloads/vehicle-technologies-office-2015electric-drive-technologies-annual-rd
- Electrical and Electronics Technical Team Roadmap: http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/eett_roadmap_jun e2013.pdf
- U.S. DRIVE Vehicle Systems Analysis Technical Team and Grid Interaction Technical Team R&D Roadmaps. http://energy.gov/sites/prod/files/2014/02/f8/vsatt_roadmap_june2013.pdf , http://energy.gov/sites/prod/files/2014/02/f8/gitt_roadmap_june2013.pdf
- Vehicle System R&D Annual Progress Report for FY2015 – Describes all Vehicle Systems R&D projects funded by DOE Vehicle Technologies Office (VTO) at a national laboratory or in partnership with industry. http://energy.gov/eere/vehicles/downloads/vehicle-technologies-office-2015-vehicle-systemsannual-progress-report

EDT G&I Conclusion

- EDT Q3: Demonstrate an electric machine which does not use rare earth materials that can achieve a specific power density of $\geq$ 1.6 kW/kg and volumetric power density of $\geq$ 5 kW/liter
- EDT Q4: Test and confirm performance SOA (30 kW) commercial module-based, liquid-cooled all-SiC traction drive inverter to analyze efficiencies under light load conditions.
- FY17 Goal: charging improvements to support long term cost effectiveness of EVs - develop an infrastructure plan to address both near and long term PEV charging needs at local, regional and national levels, including multiple scenarios based on a range of technology and consumer adoption possibilities.

Contact

Steven Boyd
steven.boyd@ee.doe.gov
(202) 586-8967

Susan Rogers
susan.rogers@ee.doe.gov
(202) 586-8997

Lee Slezak
lee.slezak@ee.doe.gov
(202) 586-2335