OAK RIDGE
National Laboratory

High Power and Dynamic Wireless Charging of Electric Vehicles (EVs)

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June 13, 2019 Project ID: ELT197

ORNL is managed by UT-Battelle, LLC
for the US Department of Energy

Overview

Timeline

- Start Date: FY19
- End Date: FY21
- 25% Complete

Barriers

- **Power Density**: Developing a compact vehicle assembly which can safely receive 200+ kilowatt (kW) power dynamically
- **Interoperability**: Realizing a system level architecture which will enable efficient power transfer for different power levels, vehicle classes, and use-cases
- **Controllability:** Identifying and implementing a control and communication system which will safely transfer power efficiently at highway speeds (70 miles per hour [mph])
- **Cost**: Achieving overall feasibility by identifying the optimal architecture (vehicle component cost and infrastructure cost) to enable economic feasibility

Budget

- Total project funding
  - DOE share – 100%
- Funding for FY19: $4M

Partners

- **Idaho National Laboratory**
- **National Renewable Energy Laboratory**
- **ORNL Team Members:** Omer Onar, Jason Pries, Rong Zeng, Gui-Jia Su, David Smith, and Burak Ozpineci

Any proposed future work is subject to change based on funding levels

Relevance – Project Objectives

Overall Objective: Analyze, design, build, and validate a vehicle integrated high power and dynamic wireless electric vehicle (EV) charging system which is viable when applied to real world traffic conditions in the U.S.

- Study and analyze existing state-of-the-art (SOA) dynamic wireless EV charging systems to identify barriers to economic viability
- Explore novel solutions which translate to or aid in gain significant performance improvement thereby improving system level feasibility
  - Novel materials
  - Novel technology
  - Infrastructure solutions
  - Analytical and simulation models of dynamic wireless charging system
- Design, build, and validate an optimized vehicle integrated high efficiency, high power density dynamic wireless EV charging system

FY 2019 Objectives:

- Complete a thorough study of the state-of-the-art dynamic wireless charging to identify metrics to enable economic feasibility
- Identify and evaluate novel technologies to enable high-power density and high-misalignment tolerant dynamic wireless power transfer system
- Develop time-varying analytical and simulation models to predict dynamic wireless power transfer (DWPT) system behavior to be used for optimal control strategy implementation
- Identify system level architectures (couplers, resonant stage, power electronics, and control) suitable for feasible dynamic charging of light-duty (LD) and medium- and heavy- (MD/HD) duty EVs

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FY19 Milestones and Go/No-Go Decision

Oak Ridge National Laboratory

Date	Milestones and Go/No-Go Decision	Status
Q1	Milestone: Complete a thorough study of data from state of the art dynamic wireless EV charging demonstrations to determine technology gaps and identify barriers to economic viability. Identify key metrics and set targets that should be realized for feasible DWPT.	Complete
Q2	Milestone: Identify and evaluate novel technologies and materials to enable high-power density and high mis-alignment tolerant WPT coupler mechanisms to enable feasible high power dynamic wireless charging.	Complete
Q3	Milestone: Develop time-varying simulation models and the dynamic inductive charging emulator (DICE) to predict and evaluate behavior of WPT couplers and resonant networks for dynamic wireless charging which can be used to predict dynamic WPT system behavior and estimate the amount of average power that can be transferred for different coupler architectures as a function of speed.	On Track
Q4	Milestone: Identify candidate WPT coupler and resonant architecture, which will meet the previously identified feasibility targets for dynamic wireless charging of LD and MD/HD EVs. Complete system level design of an optimized dynamic wireless charging system with the compact ground assemble capable of transmitting 200 kW.	On Track
Q4	Go/No-Go Decision: If the high-level cost study indicates feasibility, proceed with system optimization and hardware prototype development.	On Track

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FY19 Milestones and Go/No-Go Decision

National Renewable Energy Laboratory

Date	Milestones and Go/No-Go Decision	Status
Q1	Milestone: Complete development for driving model of EV with DWPT infrastructure. Preliminary formulation for DWPT system cost function.	Complete
Q2	Milestone: Complete data analysis for energy consumption, driving speed and travel distance for LD vehicle Transportation Secure Data Center (TSDC) database. Complete formulation for system cost function. Complete design optimization analysis for DWPT parameters (power, road coverage, battery size and track length and locations) for LD vehicles on primary and secondary roads. Complete assessment analysis for different charging scenarios (DWPT with charge sustaining, charge extension and charge depletion, stationary WPT and DC fast charging.	Complete
Q3	Milestone: Complete verification analysis for DWPT design of LD vehicles using real-world driving data and actual road networks WPTSim tool. Complete data analysis for energy consumption, driving speed and travel distance for MD/HD vehicle using INRIX and FleetDNA databases.	On Track
Q4	Milestone: Complete design optimization analysis for the key parameters of DWPT system for MD/HD vehicles (battery capacity and number of wireless pads on the vehicle).	On Track

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FY19 Milestones and Go/No-Go Decision

Idaho National Laboratory

Date	Milestones and Go/No-Go Decision	Status
Q1	Milestone: Kick-off meeting with ORNL for project coordination Literature review and software selection and purchase.	Complete
Q2	Milestone: Develop electromagnetic simulation model which will be used for shielding design. Gather requirements for data acquisition and testbed platform.	Complete
Q3	Milestone: Develop data acquisition methodology for DWPT.	On Track
Q4	Milestone: Work with ORNL and carry out EM emission test for the latest ORNL WPT. Provide preliminary passive shielding solutions to ORNL based on simulation or preliminary test at INL.	On Track

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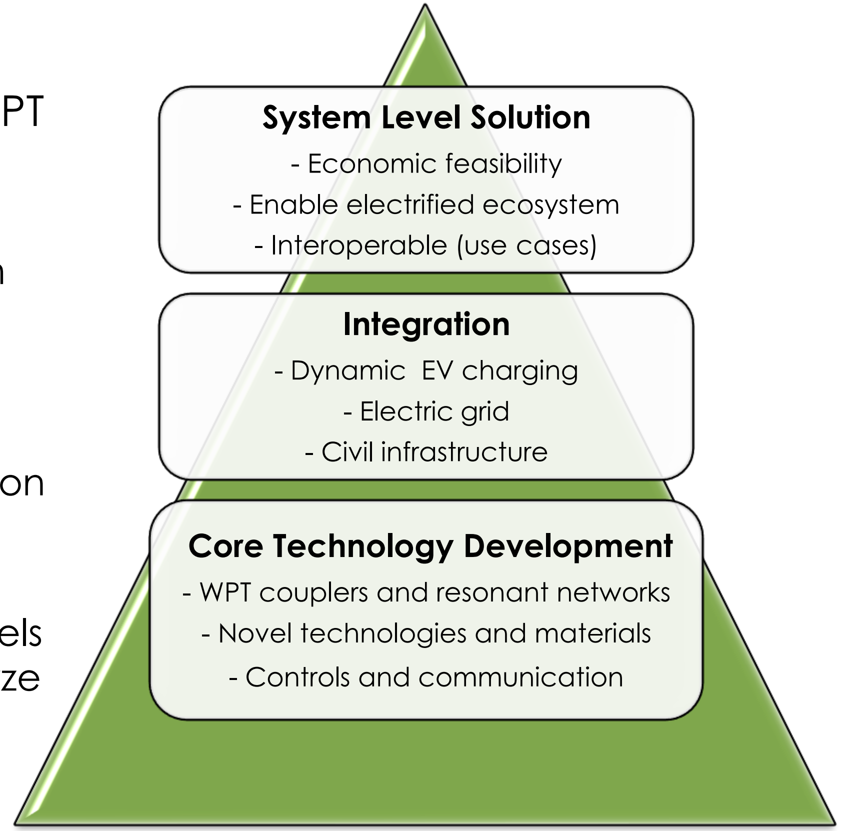
Approach

Goal: Conduct research to develop an analytical and design framework to optimize a dynamic wireless EV charging system which includes the effect of the relative movement between the WPT couplers

- Identify the optimal power transfer level and architecture for realizing a real-world feasible system
- Develop an optimized power transmitter coil architecture which can efficiently transmit power across different vehicle platforms
- Identify resonant network, control and communication architecture to enable power transfer efficiently, safely, and with interoperability
- Develop system level analytical and simulation models of dynamic wireless power transfer system to – analyze the impact on grid, evaluate interoperability for different use cases, optimize control architecture
- Build and validate high-power real world applicable dynamic wireless EV charging system



Impact: significantly increase the range of LD and MD/HD EVs while concurrently reduce the EV battery size

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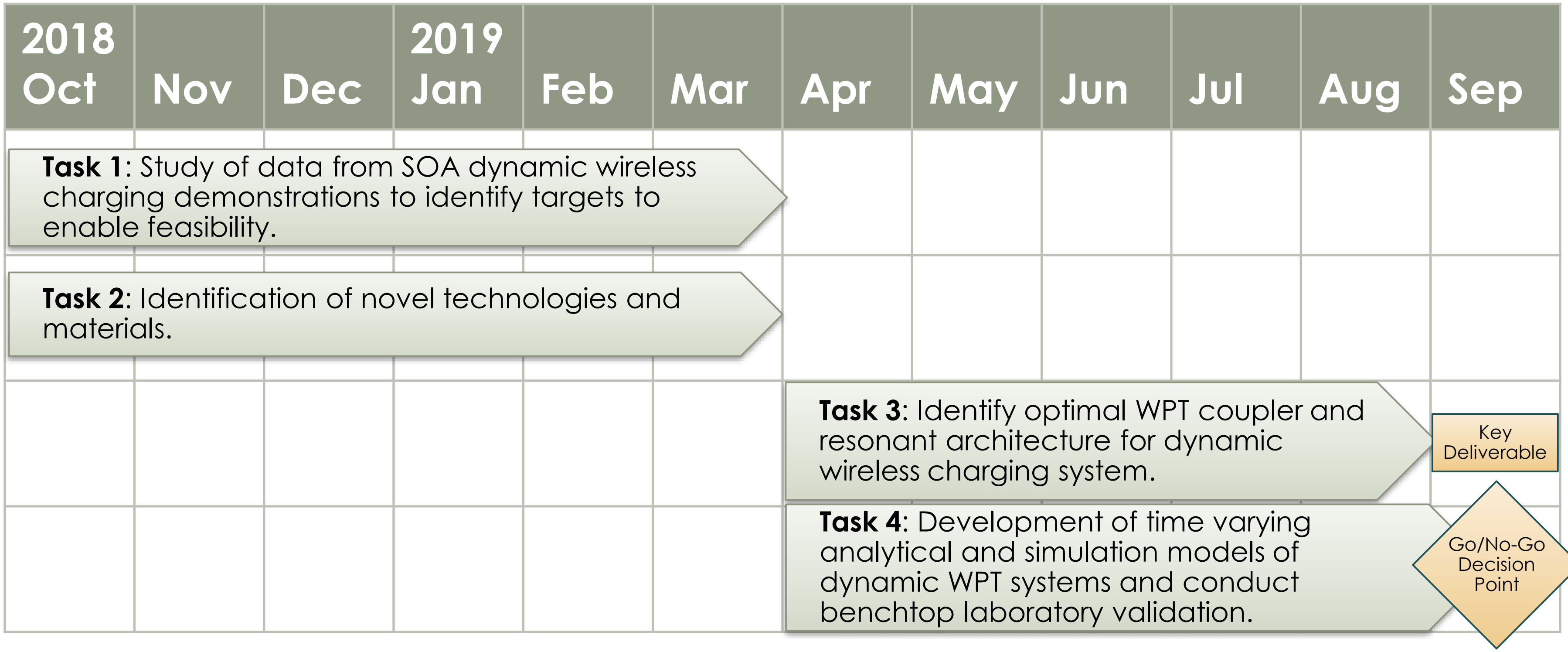
FY19 Timeline – ORNL



Go/No-Go Decision Point: If the high-level cost study indicates feasibility, proceed with system optimization and hardware prototype development

Key Deliverable: Project report detailing the analyses and discussion on feasibility study and optimal system architecture selection for high power dynamic wireless EV charging system

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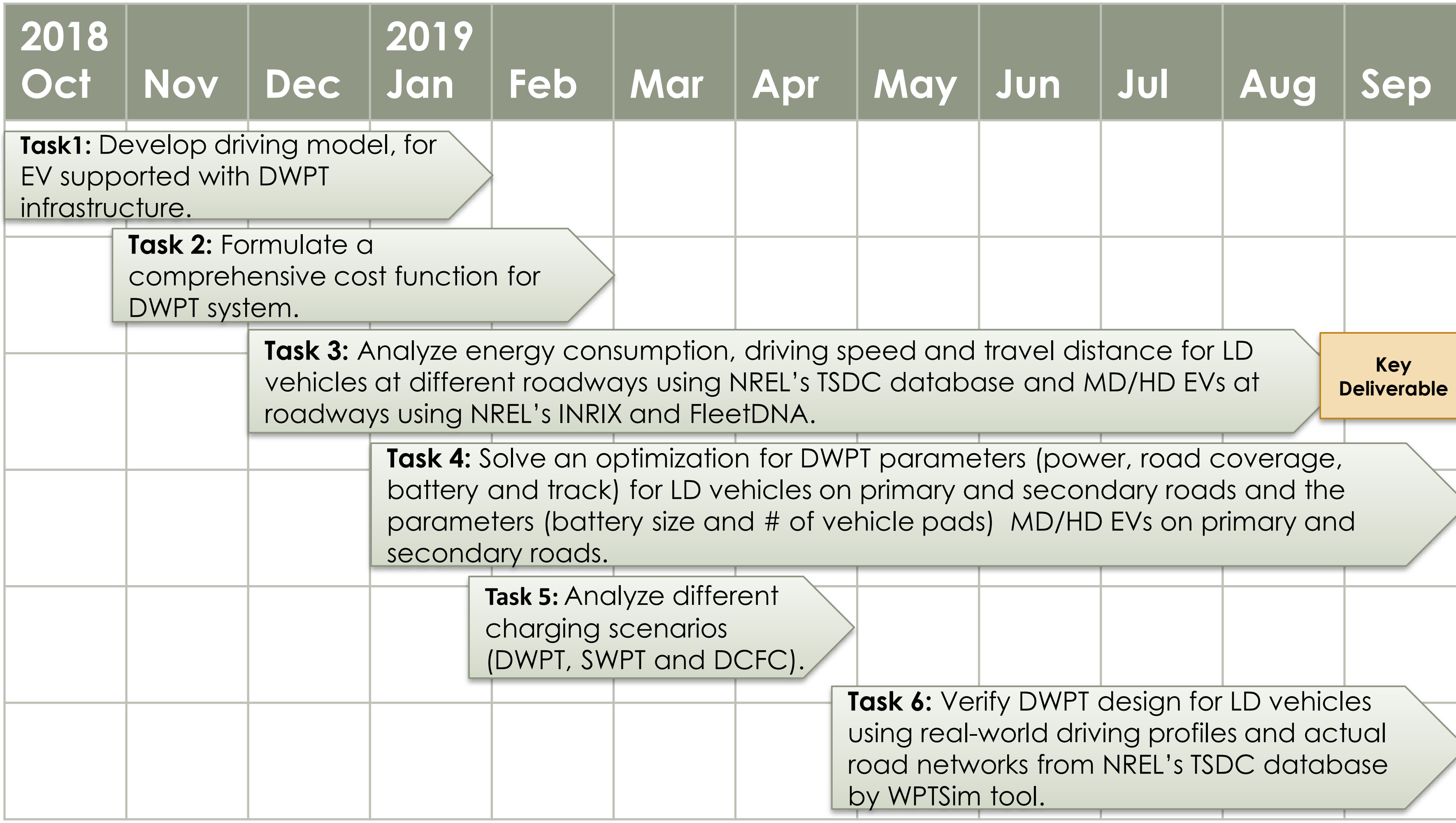
FY19 Timeline – NREL



Key Deliverable: Project report detailing the design optimization analysis and the requirements of DWPT system (power level, road coverage, battery capacity, track length and placement) for LD/MD/HD vehicles on different roadways

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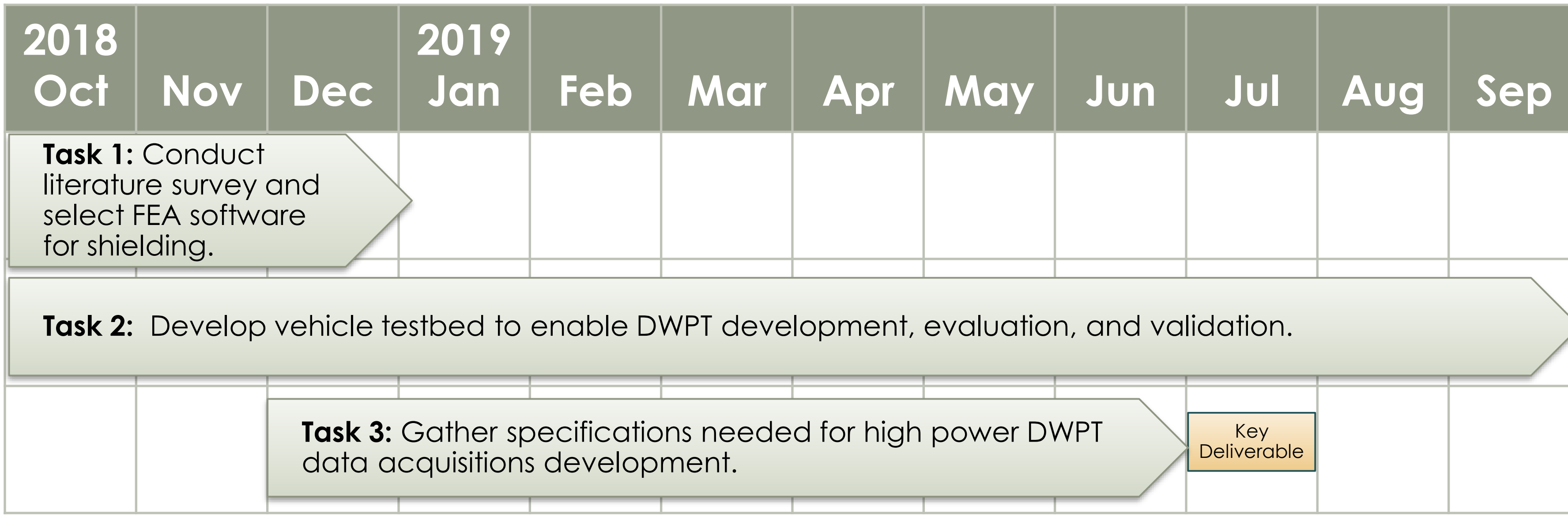
FY19 Timeline – INL



Key Deliverable:

- **July 2019 -** Data acquisition methodology developed for dynamic WPT

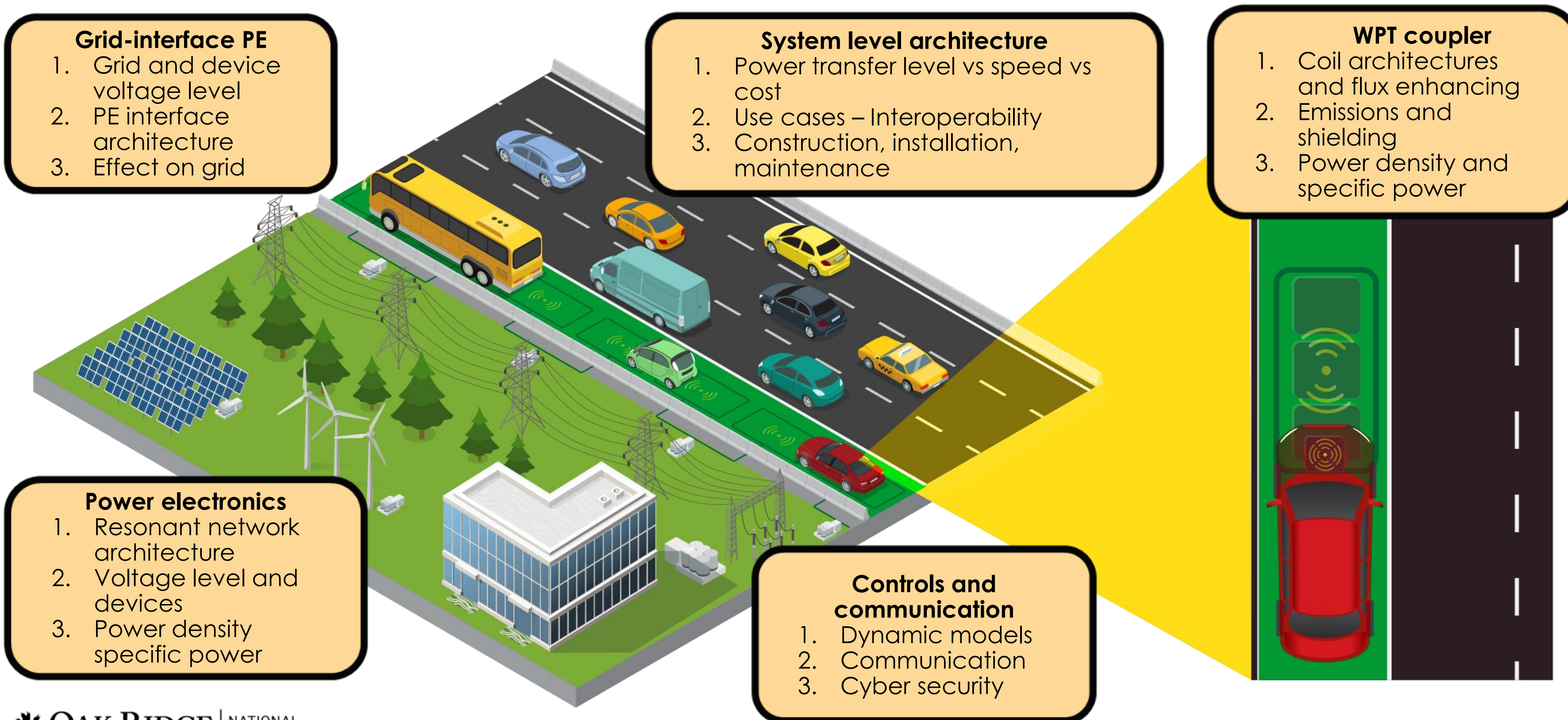
Technical Accomplishments (ORNL) – FY19

Analyzed Technology Gaps and Barriers to Economic Viability

Goal: Identify technology gaps and barriers that must be over come to enable efficient and viable dynamic wireless charging

Issue: A comprehensive study focusing on the challenges of implementing a dynamic wireless charging and its effect on electrified ecosystem is necessary

- Most of the existing dynamic charging solutions are extensions of static solutions



Technical Accomplishments (ORNL) – FY19

Analyzed Technology Gaps and Barriers to Economic Viability

Barriers	Solution	Required
Cost	• Identify optimal power transfer level and placement of charging systems based on real-world traffic data (US driving data) • Develop methodologies for system level optimization (infrastructure cost vs vehicle component cost)	• **Feasibility analyses**
Efficiency	• Optimize WPT system for net energy transfer efficiency during dynamic charging (as opposed to aligned case)	• **DWPT Co-optimization** • **Real-time and dynamic simulation and analytical models**
Interoperability	• Develop WPT couplers and resonant network capable of transferring power efficiently across vehicle classes (power level and ground clearance)	
Impact on the grid	• Develop real-time system-level simulation models to assess the effect on the grid due to numerous use cases of dynamic charging. Determine the requirement of front-end power electronics for dynamic charging. • Use the simulation models to investigate the effect of suing medium voltage connection	
Standardization	• System level studies and dynamic simulation (FEA and real-time circuit simulations) can help benchmark and assess bassline for interoperability	

Technology Gaps	Effect	Required
Specific power and power density of vehicle assembly	• Larger and heavier coils • Lower power transfer rates	• **Novel WPT technologies (polyphase systems)** • **Novel materials**
Communications and controllability	• Control scheme must enable interoperability • Communication latencies need to be accounted for	• **Dynamic stability and optimal control analyses** • **Realtime control/hardware- in-the-loop simulation models**
Impact on infrastructure	• Effect of pavement on WPT coils • Effect of electromagnetic (EM) fields on pavement material	• **Novel magnetic pavement materials** • **Characterization and study of infrastructure on magnetics (and vice versa)**

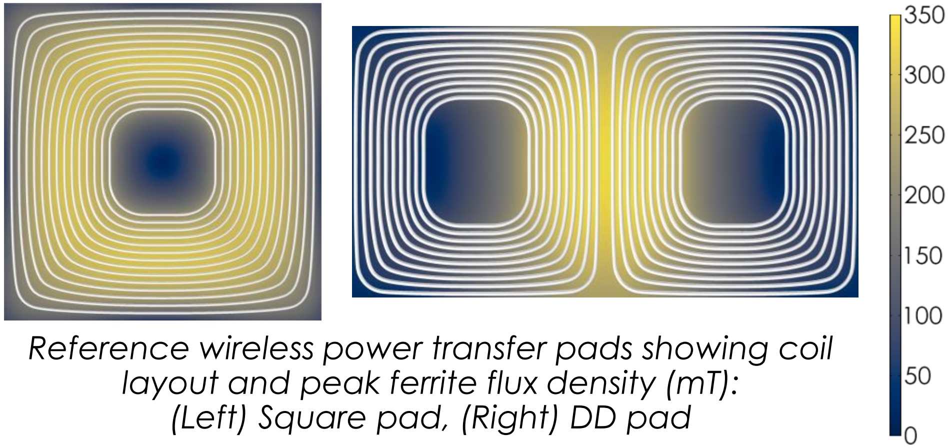
Technical Accomplishments (ORNL) – FY19

Designed Reference Pads for Dynamic WPT Control System Studies

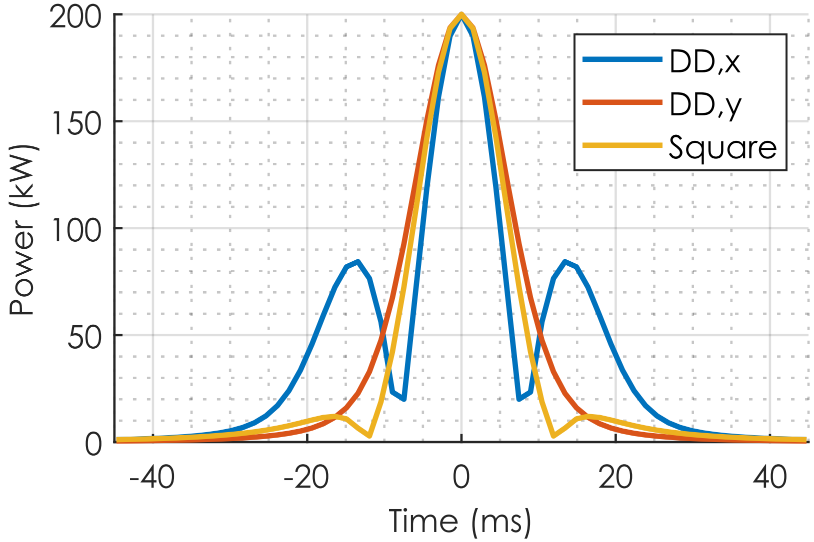
Specifications:
- Airgap: 250 millimeters (mm)
- Power: 200kW
- V_{dc}/V_{bat}: 800 volts (V)
- Tuning: Series/Series or LCC/LCC

Goal: Examine power transfer profiles for matched WPT transmitter/receivers optimized for stationary specific power capability (kW/kg)

Receiver	Square	DD	
		x	y
Length	51.2cm	81.6cm	
Width	51.2cm	43.8cm	
Mass	9.6kg	17.0kg	
Effective Power	93kW	80kW	129kW
Specific Power	9.7kW/kg	4.7kW/kg	7.6kW/kg
Simulated Energy Transfer Efficiency	80.5	82.8	82.3



Reference wireless power transfer pads showing coil layout and peak ferrite flux density (mT): (Left) Square pad, (Right) DD pad



Reference pad power profiles assuming a vehicle velocity of 75MPH (33.5m/s)

Technical Accomplishments (ORNL) – FY19

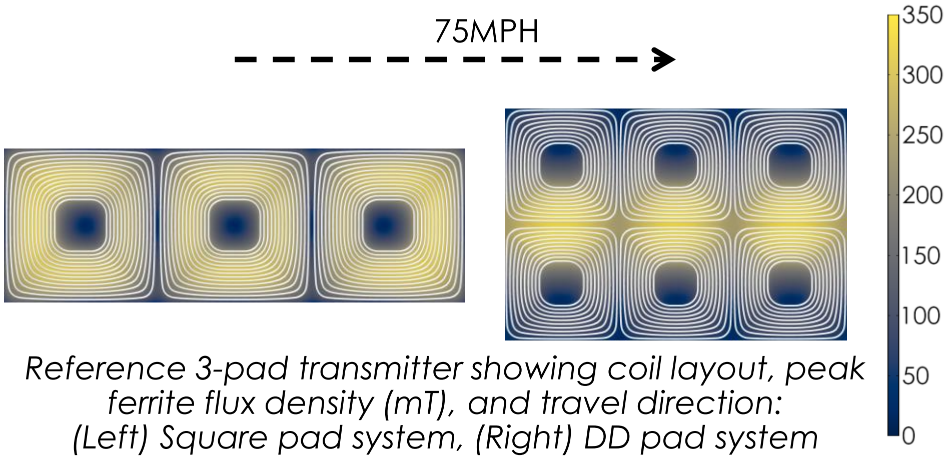
Analyzed Power Transfer Profile of Multi-Transmitter System

Issue: Square coils have degraded performance in multiple transmitter systems

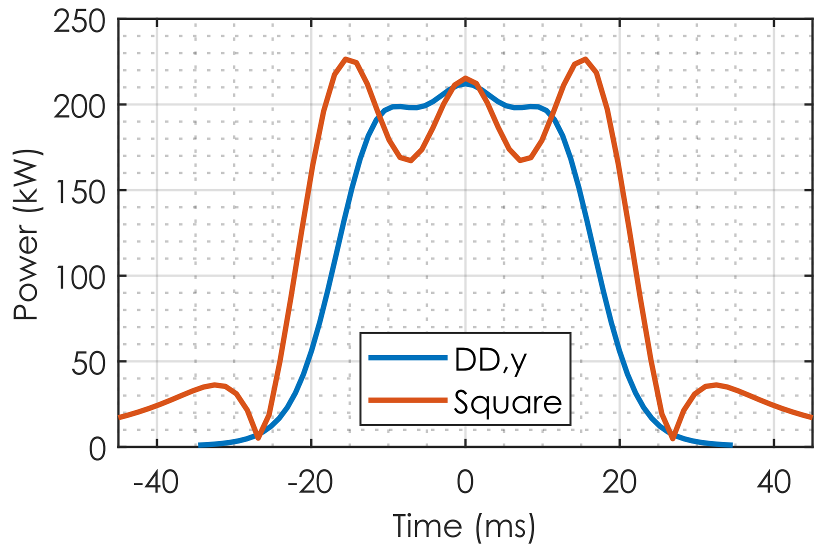
- Lower effective power due to magnetic coupling interference
- High power ripple
- Control issues (series tuning)

Goal: Refine reference pad design for 200kW peak power in a multi-transmitter, single receiver system

Receiver	Square	DD
Length	52.2cm	78.7cm
Width	52.2cm	38.7cm
Mass	10.2kg	14.5kg
Effective Power	211kW	208kW
Specific Power	20.7kW/kg	14.3kW/kg
Power Ripple	48kW	14kW
Ripple Frequency	17.5Hz	13.0Hz
Simulated Energy Transfer Efficiency	87.9	89.7



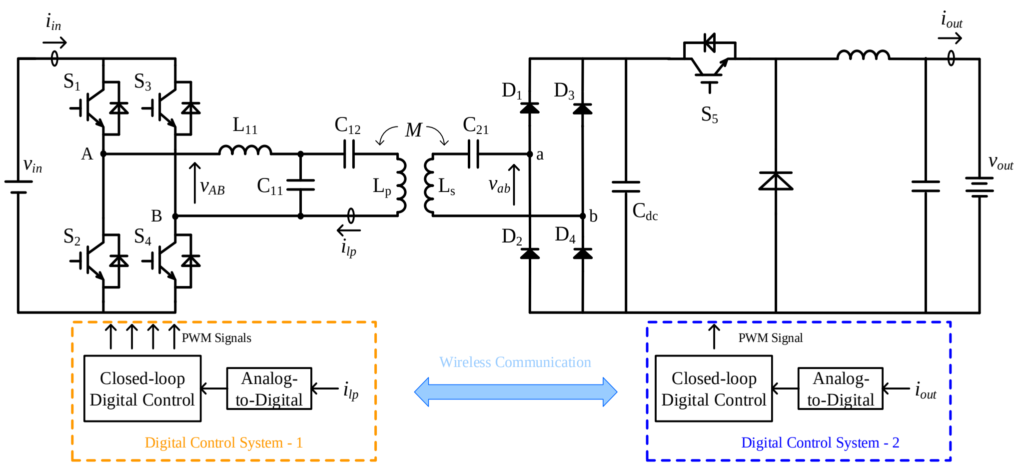
Reference 3-pad transmitter showing coil layout, peak ferrite flux density (mT), and travel direction: (Left) Square pad system, (Right) DD pad system



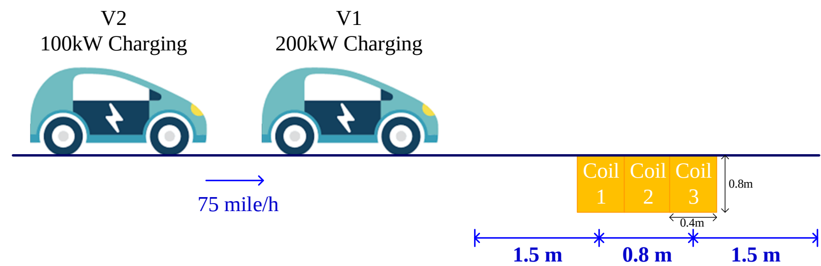
Reference pad power profiles assuming a vehicle velocity of 75MPH (33.5m/s)

Technical Accomplishments (ORNL) – FY19

Multiple Coils Transferring Different Power Levels



High-level control architecture for dynamic wireless EV charging

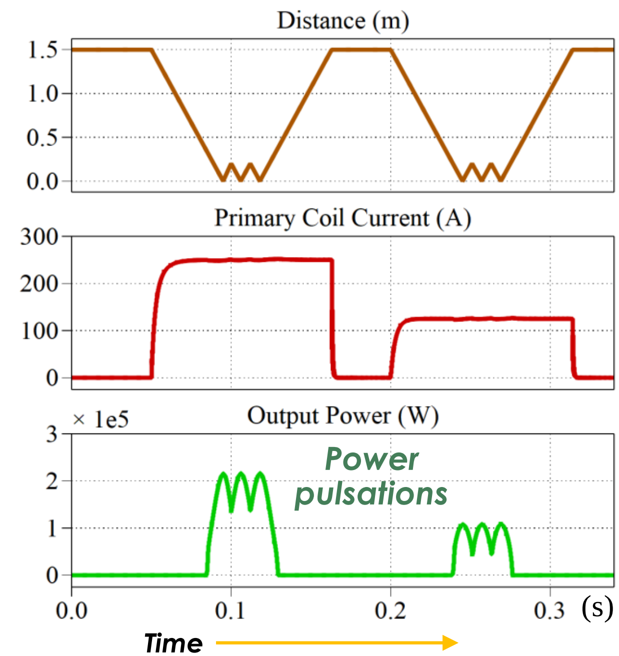


Scenario of two successive vehicles demanding different power levels

Goal: Transmitter system must be capable of charging EVs that require different power levels.

Challenges:

- Possible with primary side control, but may not be optimal. Will require optimization and/or secondary side control
- Power pulsations, control timing, communication latencies, and dynamic response time need to be considered



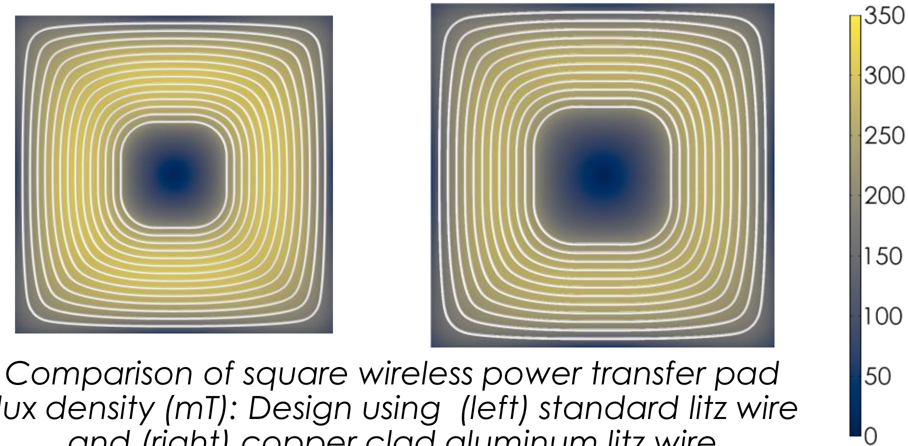
Simulated waveform of primary coil current control

Technical Accomplishments (ORNL) – FY19

Compared Reference Coil Designs using Standard and CCA Litz Wire

Specifications:
- Airgap: 250mm
- Power: 200kW
- V_{dc}/V_{bat}: 800V
- Tuning: Series/Series or LCC/LCC

Goal: Examine the impact of copper clad aluminum (CCA) litz wire on power density and specific power



Comparison of square wireless power transfer pad flux density (mT): Design using (left) standard litz wire and (right) copper clad aluminum litz wire

Receiver	Standard	CCA
Length	51.20cm	55.40cm
Width	51.20cm	55.40cm
Thickness	1.55cm	1.72cm
Mass	9.6kg	6.6kg
Power Density	76.3W/cm^2	65.2W/cm^2
Specific Power	20.8kW/kg	30.3kW/kg

Aluminum strand with copper cladding to reduce effective wire resistance while mitigating skin effect

Technical Accomplishments (NREL) – FY19

Optimal Placement and Sizing of Dynamic WPT System for Feasibility

Goal: Identify optimal power transfer level, roadway coverage, battery capacity, and placement of dynamic charging for LD/MD/HD vehicles at primary and secondary roadways.

Issue: Several trade-offs which can affect overall feasibility while indicating sub-system optima: infrastructure cost, vehicle component cost, charge rate, battery cost, and power transfer level.

Methodology:

- Using real-world collected data for vehicle energy consumption at different roadways
- Optimizing DWPT system key design parameters for cost-effective and charge sustaining
- Evaluate the optimal design using real-world driving profiles and actual road network

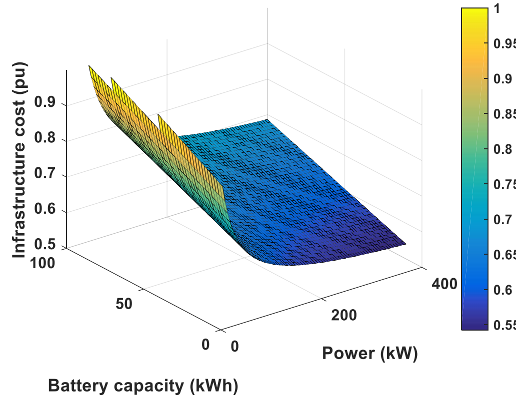
Accomplishments:

- Analyzed representative range of energy consumption, driving speed and travel distance for LD vehicles on different types of roadways using actual collected data from NREL's TSDC database.
- Formulated a comprehensive cost function for DWPT system, considering road infrastructure and vehicle component cost, which includes:
    - Road retrofitting cost;
    - Power electronic, material and resonance network costs for primary and secondary sides; and
    - Battery cost as function of C-rate and SOC window.
- Analyzed and compared different charging scenarios, considering DWPT, Stationary WPT and DCFC.

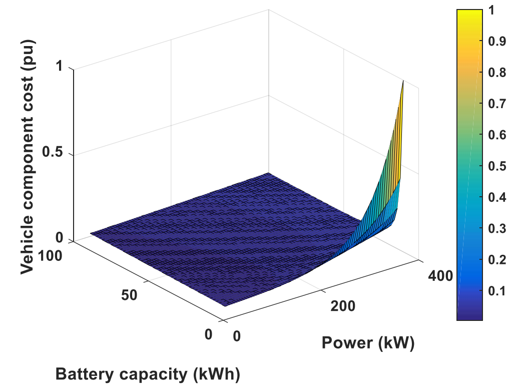
Technical Accomplishments (NREL) – FY19

Design Optimization Results

- **Specification:** For a 300 miles primary roadway with 1 electrified lanes per road, with ΔSOC=20%
- As power level increases, infrastructure cost reduces but the vehicle component cost increases
- Higher charge rate leads to lower overall cost – optimal charge rate ~ 12



Infrastructure component cost



Vehicle component cost

Total Cost with $C_{rate} < 2$

Parameter	Value
Min total cost (pu)	0. 3557
Battery capacity	56 kWh
Charging rate	124 kW
Road coverage	24.75%
# DWPT positions	7
Nonelectrified distance	33.7 miles
Electrified distance	11 miles
C_{rate}	**1.99**

Total Cost with $C_{rate} < 6$

Parameter	Value
Min total cost (pu)	0.3153
Battery capacity	30 kWh
Charging rate	199 kW
Road coverage	14.39%
# DWPT positions	13
Nonelectrified distance	19.4 miles
Electrified distance (L_T)	3.25 miles
C_{rate}	**5.98**

Total Cost Optimized with unrestricted C_rate

Parameter	Value
Min total cost (pu)	0. 3057
Battery capacity	16 kWh
Charging rate	215 kW
Road coverage	12.86%
# DWPT positions	24
Nonelectrified distance	10.74 miles
Electrified distance (L_T)	1.6 miles
C_{rate}	**12**

Technical Accomplishments (NREL) – FY19

Comparison of Dynamic Charging with Stationary Wireless Charging and DC Fast Charging

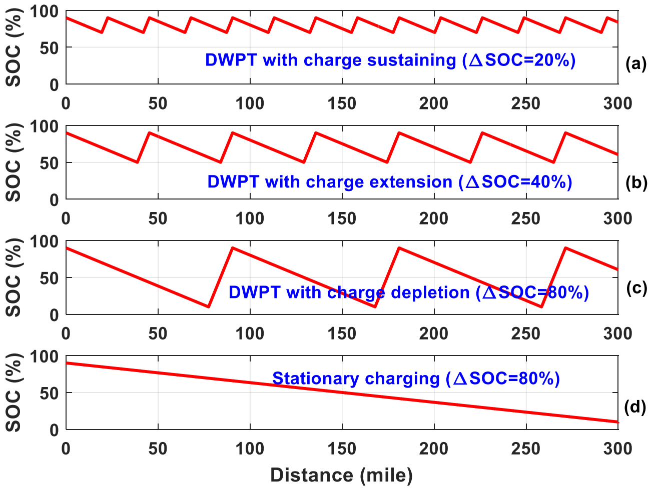
Accomplishments: Evaluated effect of dynamic wireless charging, stationary wireless charging and DC fast charging combination on total component cost

Stationary Wireless Charging with DC Fast Charging

- **Specification**: 300 miles range on-board battery with 5-10 minutes recharging time
- 158 kWh battery will be required with 950 kW stationary charging capability for 80% SOC window. It leads to about 5.4 C-rate
- Challenge: 1 MW charger,150 kWh battery pack required, 6 C rate for 80 % ΔSOC.

Dynamic Wireless Charging has the lowest overall cost due to increased utilization of charger, low power battery pack, and low SOC window

Performance parameter	DWPT (ΔSOC=20%)	SWPT (ΔSOC=80%)	DCFC (ΔSOC=80%)
Vehicle components cost	Low	High	Medium
Road components cost	High	High	High
Total cost	Medium	Very High	High
Automatic	Yes	Yes	NO
Recharge time	Zero	8 minutes	8 minutes
Land requirement	Not required	High	High
Energy consumption	Low	High	High

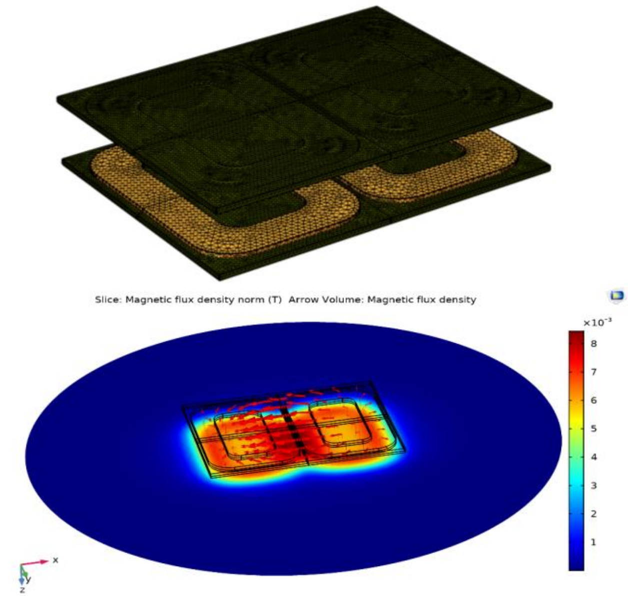


Optimal solutions for secondary roads are: 1) 16 kWh battery pack with 120 kW DWPT and 16.88 % road coverage → 7 C rate battery; and 2) if C rate is limited to 3 → 30 kWh battery pack and 91.26 kW DWPT

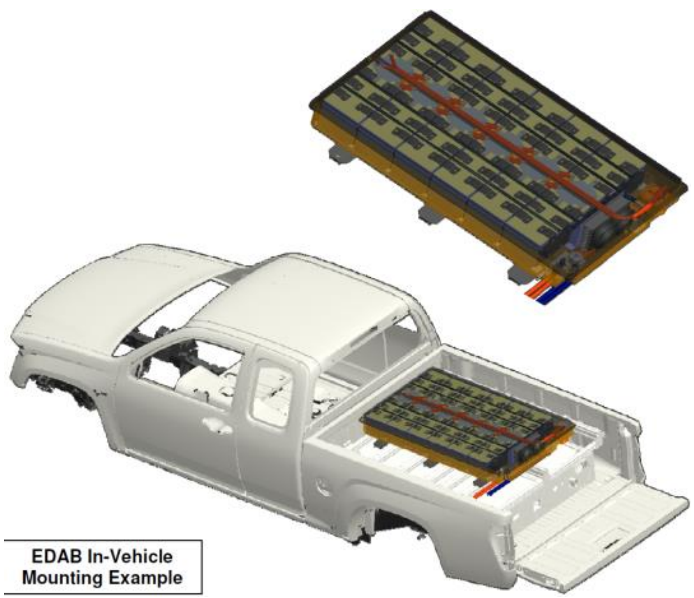
Technical Accomplishments (INL) – FY19

Shielding/Flux Shaping Study and Dynamic WPT Test bed Specification Gathering

Goals:
- To evaluate and develop shielding techniques necessary for dynamic wireless EV charging
- Develop a test-bed for high power dynamic wireless EV charging vehicle test bed (real-world conditions)



3D Magnetic field simulation using COMSOL



Electric Drive and Advanced Battery and Components testbed (EDAB)

Accomplishments:
- Developed and validated 3D FEA models of base line stationary wireless EV charging couplers
- Finalizing the specifications for Electric Drive and Advanced Battery and Components testbed (EDAB) testbed: 200 kW+ static and DWPT, ~ 8C charge rate, 650 VDC, cooling configuration, communication requirements, and auxiliary load assessment

Technical Accomplishments (INL) – FY19

Data Acquisition Requirements

Goals:

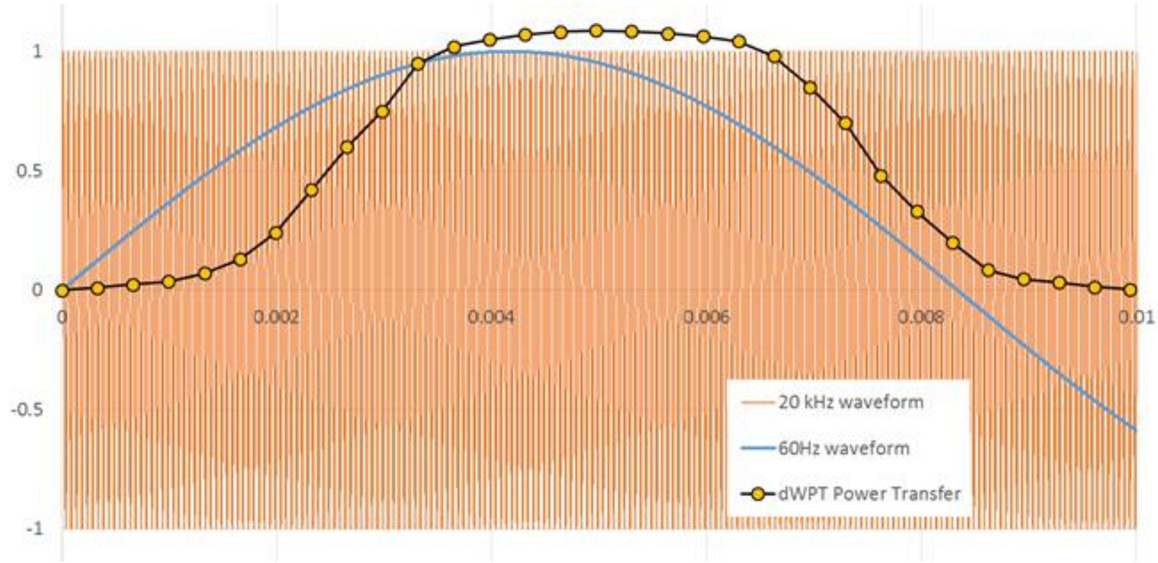
- Evaluate the requirements of data acquisition system for a high-speed high-power dynamic wireless EV charging system

Accomplishments:

Identified measurement requirements and challenges, capabilities required include

Challenges:

- < 1 cycle of 60Hz occurs during dynamic WPT cycle
- Many, many 20 kHz (or 85 kHz) cycles during dynamic WPTcycle
- Measurement of the dynamic WPT (i.e. DC to DC) needs to be ~ 3 kHz at a minimum



Measurement frequencies of dynamic WPT system

Response to Previous Year Reviewers' Comments

This project is a new start

Oak Ridge National Laboratory | National Transportation Research Center

Collaboration and Coordination with Other Institutions

NREL NATIONAL RENEWABLE ENERGY LABORATORY	**National Renewable Energy Laboratory** • Analyzing the DWPT system requirements, in terms of power level, road coverage battery capacity, track length and placement for different types of roadways and vehicles to achieve system to enable feasible dynamic wireless EV charging
INL Idaho National Laboratory	**Idaho National Laboratory** • Evaluating novel shielding and field shaping techniques • Evaluating and assessing data gathering and key parameter measurements for high speed dynamic charging • Support in configuration and modification of EV testbed to evaluate real-world high power dynamic charging application

Coordination and project feedback partners:

- Mercedes-Benz Research and Development North America
- Utah State University: Characterization of mechanical and civil engineering aspects of WPT coils
- Magment: A company that manufactures magnetic cement
- Integrated Roadways: Characterization of properties of pavement per dynamic WPT requirements

Remaining Challenges and Barriers

- **Controls and communications**: Accurate dynamic models necessary to develop a control strategies are to be derived. Wireless communication latencies may pose challenges to implement optimal control strategies.
- **Validation of control strategy**: Real-time simulation and scaled-down prototype models will have to be built to validate control scheme before implementing in real vehicle. An accurate scaled-down inductive charging emulator is necessary.
- **Interoperability**: In addition to achieving magnetic interoperability, the effect of resonant network and control on interoperability needs to be evaluated.
- **Accurate cost modeling**: Getting more accurate estimation for construction work cost for DWPT infrastructure.
- **Different vehicle classes**: Mapping representative real-world drive cycles for different vehicle classes with different types of roadways.
- **EM Shielding and Interference**: Detailed shielding studies and strategies have to be devised for dynamic wireless charging. The effect of EM field on communication and sensors may have to be investigated.

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Proposed Future Research (ORNL)

- **FY 2019**
  - **Milestones**:
    - Develop time-varying simulation models and the dynamic inductive charging emulator (DICE) to predict and evaluate behavior of WPT couplers and resonant networks for dynamic wireless charging which can be used to predict dynamic WPT system behavior and estimate the amount of average power that can be transferred for different coupler architectures as a function of speed
    - Identify candidate WPT coupler and resonant architecture, which will meet the previously identified feasibility targets for dynamic wireless charging of LD and MD/HD EVs. Complete system level design of an optimized dynamic wireless charging system with the compact ground assemble capable of transmitting 200 kW
  - **Key Deliverables**: Project report detailing the analyses and discussion on feasibility study and optimal system architecture selection for high power dynamic wireless EV charging system
  - **Tasks**:
    - Development of time varying analytical and simulation models of dynamic WPT systems and conduct benchtop laboratory validation
    - Identify optimal WPT coupler and resonant architecture for dynamic wireless charging system
    - **Go/No-Go Decision**: If the high-level cost study indicates feasibility, proceed with system optimization and hardware prototype development
- **FY 2020**
    - Complete design of optimized 200 kW WPT coils suitable for dynamic WPT
    - Complete prototyping and laboratory characterization of 200 kW WPT coils suitable for dynamic WPT
    - Complete power electronics hardware design and assembly for 200 kW operation
    - Validate 200 kW WPT power transfer capability

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Proposed Future Research (NREL)

- **FY 2019**
  - **Milestones**:
    - Complete verification analysis for DWPT design of LD vehicles using real-world driving data and actual road networks WPTSim tool. Complete data analysis for energy consumption, driving speed and travel distance for MD/HD vehicle using INRIX and FleetDNA databases.
    - Complete design optimization analysis for the key parameters of DWPT system for MD/HD vehicles (battery capacity and number of wireless pads on the vehicle).
  - **Key Deliverables**:
    - Project report detailing the design optimization analysis and the requirements of DWPT system (power level, road coverage, battery capacity, track length and placement) for LD/MD/HD vehicles on different roadways
  - **Tasks**:
    - Verifying the optimal design for LD vehicles using real-world driving profiles with actual road network.
    - Analyzing and verifying the DWPT system requirements for MD/HD vesicles at different roadways.
- **FY 2020**
    - Explore the placement and operation of WPT system at traffic signals for secondary roadways.
    - Investigate WPT infrastructure requirements for vocational driven MD and HD applications using real-world collected data.
    - Assessment of different structures of wireless track (long-track or multiple pad), in terms of energy transfer using WPTSIm.

Any proposed future work is subject to change based on funding levels

Proposed Future Research (INL)

- **FY 2019**
  - **Milestones**:
    - Kick-off meeting with ORNL for project coordination
    - Meeting with sub-contractor to agree upon EDAB modifications requirements & schedule
    - Develop data acquisition methodology for dynamic WPT
    - Complete benchmarking study of state of the art shielding techniques
  - **Key Deliverables**:
    - DWPT data acquisition requirements with initial plan for implementation
    - Preliminary EM-field shaping concept
  - **Tasks**:
    - Testbed vehicle to enable Dynamic WPT development, evaluation, and validation
    - High Power Dynamic WPT evaluation and validation methodology and requirements
    - Electromagnetic Field Shaping technique suitable for safe high power and dynamic WPT

Any proposed future work is subject to change based on funding levels

Summary (ORNL)

- **Relevance**: An economically viable dynamic wireless charging system can lead to considerable increase in range of EVs and reduction in cost and size of required on-boar battery
- **Approach**: Based on a high level cost study and feasibility analyses, technical targets to enable viability will is identified. Research and development in WPT couplers, resonant networks, EM shielding and control architecture will be carried out to meet the technical targets
- **Technical Accomplishments:**
  - Conducted a thorough review of state-of-the art dynamic wireless EV charging systems and analyzed the technology gaps and barriers to economic viability
  - Designed reference high-power dynamic charging coils and initiated control architecture and energy transfer capability and efficiency studies
  - Compared reference coil designs using conventional copper Litz and copper-clad aluminum Litz wires
- **Collaborations and Coordination with Other Institutions**:
  - NREL: Identify optimal power transfer level and placement to enable economic viability
  - INL: Support in EM shielding and defining the specifications and engineering the vehicle test platform for dynamic wireless EV charging
  - Mercedes-Benz Research and Development North America
  - Utah State University: Characterization of mechanical and civil engineering aspects of WPT coils
  - Magment: A company that manufactures magnetic cement
  - Integrated Roadways: Characterization of properties of pavement per dynamic WPT requirements
- **Future Work**:
  - Complete development of dynamic models to aid in the evaluation of optimal control strategy
  - Develop real-time simulation model to evaluate the effect of communication latencies on the control strategies as applied to dynamic wireless EV charging
  - Use FEA and resonant network analyses to evaluate the interoperability of different WPT architectures
  - Identify optimal system architecture in terms of power transfer capability, efficiency, vehicle coil mass, controllability, and interoperability

Any proposed future work is subject to change based on funding levels

Summary (NREL)

- **Relevance**: Defining optimal key design parameters of DWPT system (power level, roadway coverage, battery capacity, number and positions of DWPT charger) for different vehicle and roadway classes.
- **Approach**:
  - Using real-world data for energy consumption and driving speed
  - Optimizing the DWPT system parameters for cost-effectiveness and charge sustaining operation
  - Verifying the optimal design using real-world driving profiles and actual roadway network
- **Technical Accomplishments**:
  - Analyzed representative energy consumption, driving speed and travel distance for LD vehicles on different types of roadways using actual collected data from NREL's TSDC database.
  - Formulated a comprehensive cost function for DWPT system, considering road infrastructure and vehicle component cost, which includes
  - Analyzed and compared different charging scenarios, considering DWPT, Stationary WPT and DCFC
- **Collaborations and Coordination with Other Institutions**:
  - ORNL
  - INL
- **Future Work**:
  - Verifying the optimal design for LD vehicles using real-world driving profiles with actual road network
  - Analyzing and verifying the DWPT system requirements for MD/HD vesicles at different roadways

Any proposed future work is subject to change based on funding levels

Summary (INL)

- **Relevance**:
  - EM-field shaping is a design pathway towards safe EM-field levels even at high power transfer rates
  - dWPT requires fast, synchronized data acquisition from multiple sources (some in-motion). Not a trivial problem to solve
- **Approach**:
  - Simulation and lab validation of new concepts for EM-field shaping to reduce EM-field emissions
- **Technical Accomplishments**:
  - Initial dWPT data acquisition requirements developed
  - Baseline EM-field shaping simulations completed
- **Collaborations and Coordination with Other Institutions**:
  - ORNL
- **Future Work**:
  - Further modeling and laboratory verification of EM-field shaping designs
  - EM-field measurements of state-of-the-art high power WPT systems
  - Implement dWPT data acquisition plan into EDAB testbed

Any proposed future work is subject to change based on funding levels