NSF | ASPIRE

Electrified Roadways

The Path to National Scale Roadway Electrification

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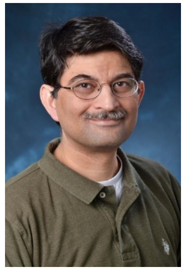

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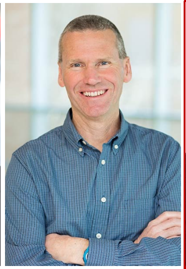

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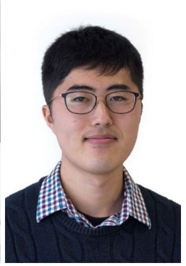

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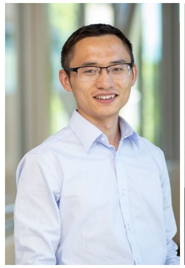


Hongjie Wang (USU)

Doug Wilson (UoA)

Regan Zane (USU)

New Team Members

Project 2 Objectives

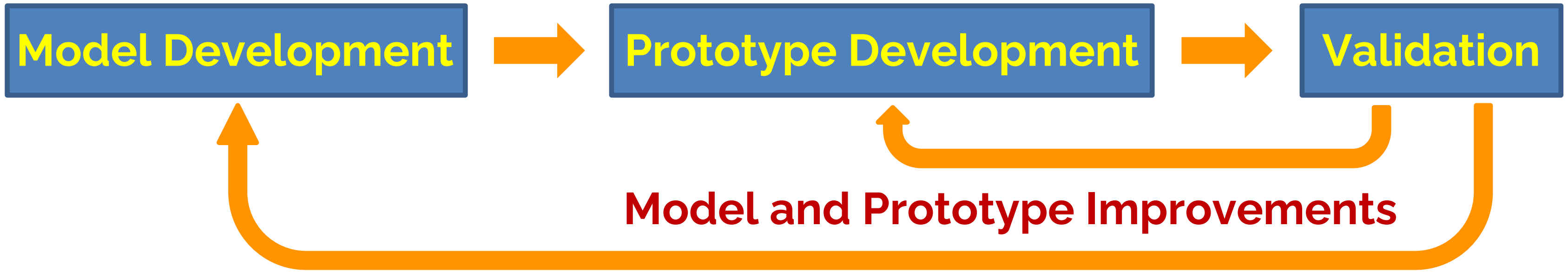
- Push performance frontier of electrified roadways with embedded dynamic and semi-dynamic wireless charging in terms of power delivery, constructability, durability, maintainability, packaging, interoperability, standards, safety, electromagnetic interference/compatibility, supporting infrastructure and accessibility

- Train diverse engineering workforce capable of developing and deploying electrified roadways

- Reduce inequities in electric vehicle charging infrastructure access through appropriate ways of deploying electrified roadways

Project 2 Approach

- Convergent research across multiple fields to cover structural, electrical, electromagnetic, thermal, economic and human aspects of electrified roadways with integrated wireless charging
- Active recruitment and mentorship of diverse group of students, staff, and faculty members
- Partner with Project 4 (Pathways) to understand inequities in electric vehicle charging infrastructure access and potential for reduction through electrified roadways



Project 2 Roadmap

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Threads and Supporting Tasks	**ER Short Term Milestones (2024-2025)** *Extended Pilots*	**ER Mid Term Milestones (2028-2029)** *Early Deployment*	**ER Long Term Milestones (2035-2040)** *Corridors and Highways*
Wireless Power Delivery (Tasks 2.1-2.2) (Center Goals 1, 3)	Deploy 200 kW concrete based dynamic systems at testbed or pilot with stakeholder engagement at power transfer density exceeding 75 kW/m² by Q4 2025.	Deploy concrete and asphalt-based systems with 95% efficiency and power transfer density exceeding 100 kW/m² by Q4 2028.	Deployments covering corner cases, such as delivering full power needed for high inclines by Q2 2035 and power covering all vehicle classes at power transfer densities exceeding 150 kW/m² and 95% efficiency by 2040.
Constructability, Durability, Maintainability & Packaging (Tasks 2.1-2.4) (Center Goals 1, 3, 5, 6)	Proof-of-concept robust inpavement charging with power electronics in roadside cabinets by Q2 2024 and examples of asphalt and concrete construction with fault-tolerant electronics by Q4 2025.	Performance-based construction practice with encapsulated electronic modules validated with contractors and trade unions by Q2 2028.	Standardized construction practices for concrete, asphalt and other materials broadly adopted by Q4 2035 and economical >30-year life pavement systems with integrated electronics for dynamic charging by 2040.
Interoperability and Standards (Task 2.3) (Center Goals 1, 3, 5, 6)	Multiple vehicle classes operable across varying ground clearance of 15-20 cm by Q1 2024 and 8-28 cm by Q3 2025.	Interoperable systems deployed in selected areas on interstate and state highways through rural areas by Q4 2029.	Widely accepted system standards enabling deployment across state boundaries by Q4 2035 and interoperability across all vehicle classes of road transportation system by 2040.
Safety and Interference (Task 2.1) (Center Goals 1, 3)	Systems designed and demonstrated to meet existing safety and interference standards by Q2 2025.	Mechanisms to deal with detection of foreign and live objects on roadways for safe operation validated in real-world environments on public roads by Q1 2028.	Electric road systems broadly accepted as being safe and non-interfering by 2040.
Supporting Infrastructure (Tasks 2.4-2.5) (Center Goals 2, 3, 5)	Accurate metering, communication and effective power distribution demonstrated in testbeds by Q4 2025.	Integration with autonomous vehicles and smart infrastructure in pilot and early deployment systems by Q2 2028.	Desirable and seamless infrastructure connecting power and transportation by 2040.
Accessibility (Task 2.6) (Center Goals 4, 6)	Approaches addressing system costs and large-scale deployment, and pilots covering user groups from underserved communities by Q4 2025.	Deployment in inner cities and underserved regions with active community engagement by Q2 2029.	Ubiquitous availability in key areas or corridors across multiple states in US and New Zealand by 2040.

Project 2 Tasks

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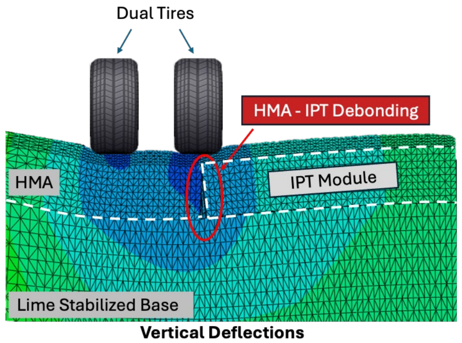
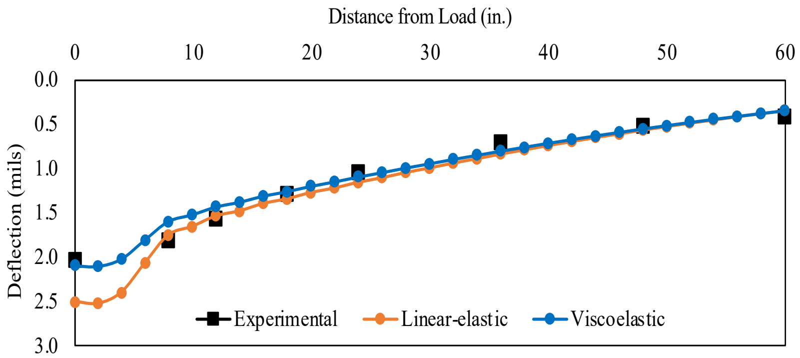
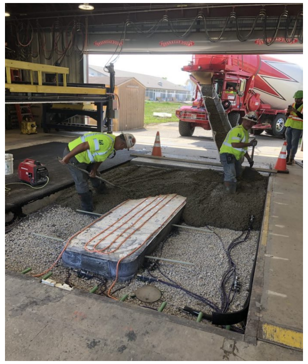
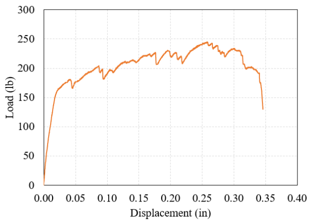
- **2.1: Modeling, Design & Implementation of Electrified Pavement Structures**
  - Leads: C. Tirado (CE, UTEP), A. Brovont (ECE, Purdue), M. Halling (CEE, USU)
- **2.2: Thermal Modeling & Evaluation of Pavement Embedded Wireless Charging**
  - Leads: N. Roberts (MAE, USU), K. Afridi (ECE, Cornell), N. Gkritza (CE, Purdue), J. Haddock (CE, Purdue)
- **2.3: Interoperability of Wireless Power Transfer Systems**
  - Leads: S. Pekarek (ECE, Purdue), R. Zane (ECE, USU)
- **2.4: Packaging of Embedded Electronics in Pavement Integrated Wireless Charging**
  - Leads: J. Lee (MAE, USU), A. Kamineni (ECE, USU)
- **2.5: Communication Infrastructure for Secure & Smart Electrified Roadways**
  - Leads: R. Hu (ECE, USU), R. Gerdes (ECE, VT)
- **2.6: Asset Management Framework for Electric Road Systems**
  - Leads: A. Raheem (CE, UTEP), C. Torres-Machi (CEA, CU Boulder), J. Goodridge (EF, USU)

Electrified Pavement Structures









- Modeling, designing and implementing electrified pavement structures with inductive dynamic wireless power transfer (DWPT) systems
- Incorporated high-power inductive DWPT into pavement modeling tool to predict behavior of concrete (rigid) and asphalt (flexible) electrified roadways
- DWPT system integrated into concrete and asphalt pavements and tested by conducting 65,000 passes at accelerated pavement testing (APT) facility
- Enhanced accuracy of structural modeling tool by incorporating viscoelastic constitutive material models and validated models using APT data
- Identified engineered cementitious composites (ECC) as durable concrete mixture for electrified pavements due to its micro-cracking properties and high fatigue resistance
- Evaluating structural response of conventional and higher-grade asphalt binders under accelerated loading conditions

Three-Phase Dynamic Wireless Charging

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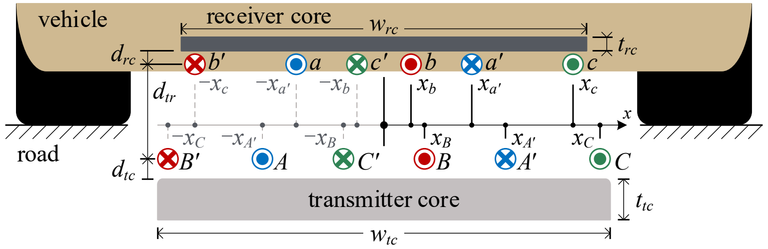

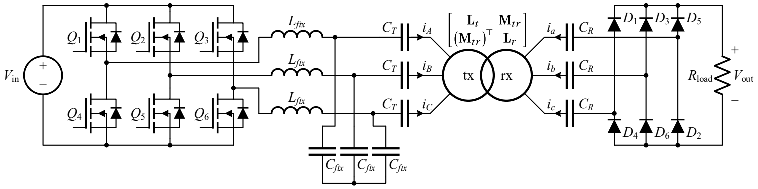

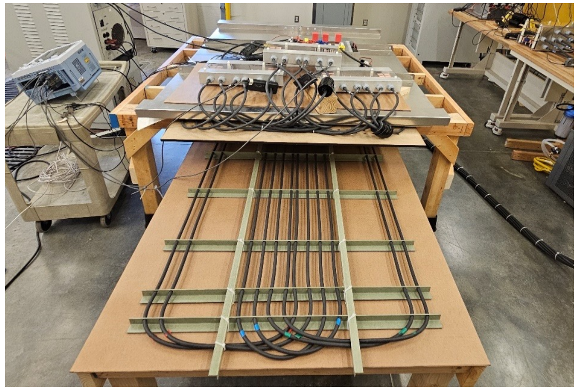

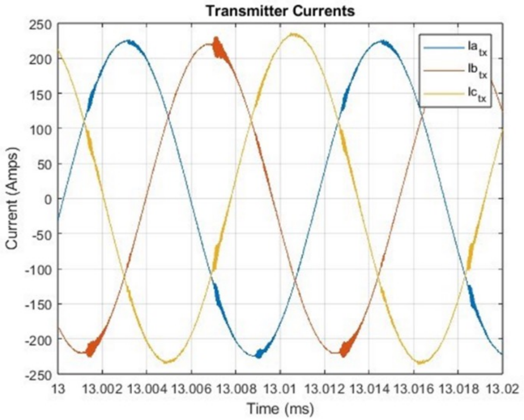

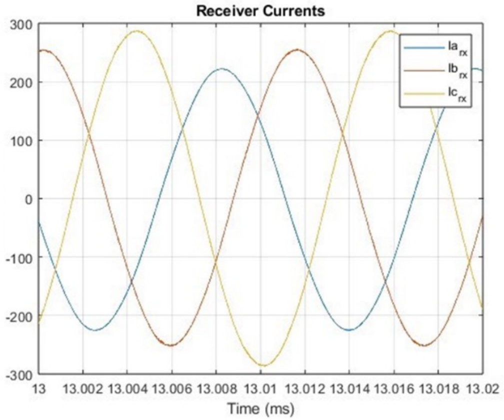

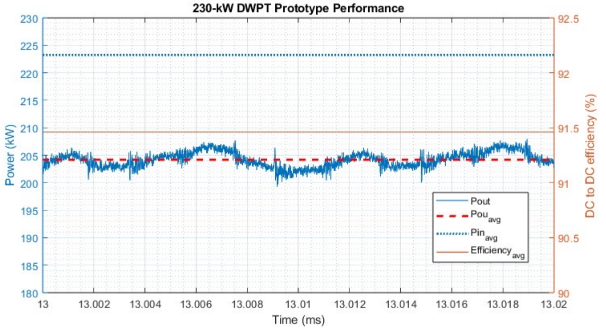

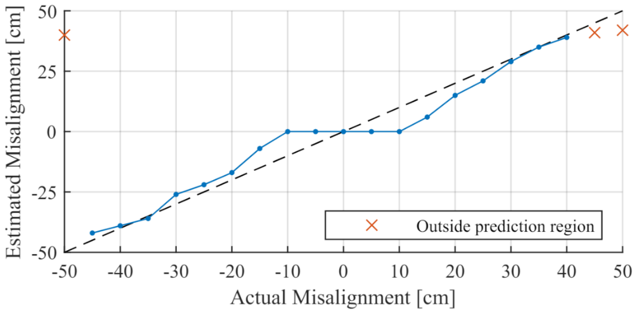

- Developed three-phase inductive DWPT system with transverse magnetic poles (relative to travel direction) to reduce power oscillations and enable straightforward power scaling by extending length
- APT test data leveraged to design 230 kW, 79-90 kHz inductive DWPT system for an INDOT pilot whose construction started in Spring 2024
- Measured DC-to-DC efficiency of this DWPT system utilizing SiC-based three-phase inverter at 200 kW output power is 91.4%
- This DWPT system has low phase current imbalance and power ripple
- Developed algorithm to predict transmitter/receiver lateral misalignment using only receiver-side measurements — algorithm based on ratio of positive- and negative-sequence values of receiver currents

Wireless Charging Thermal Modeling

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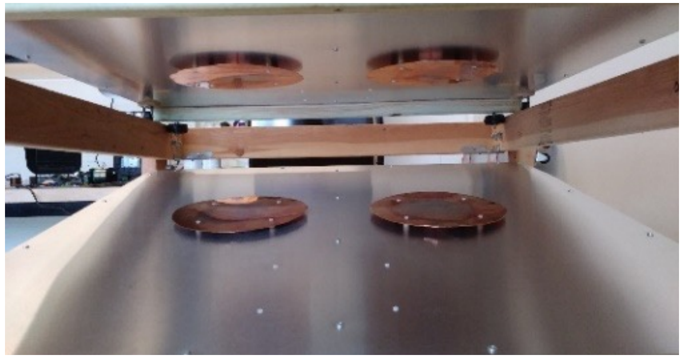

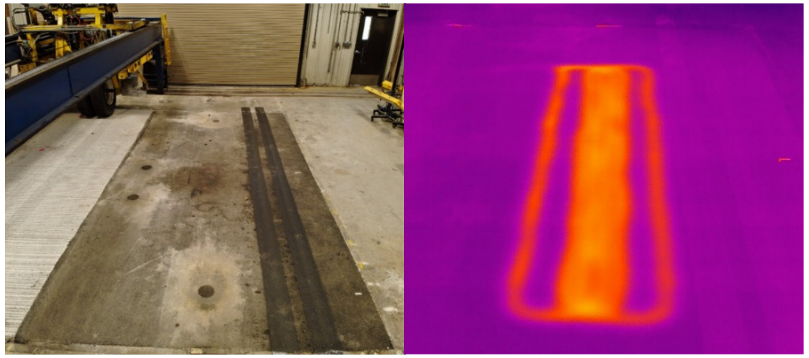

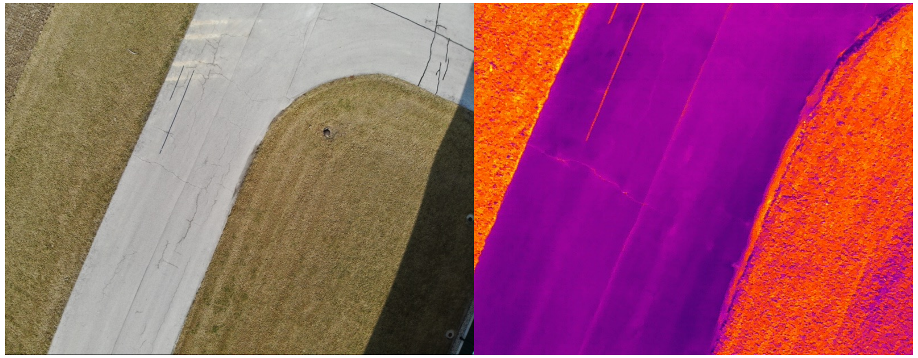

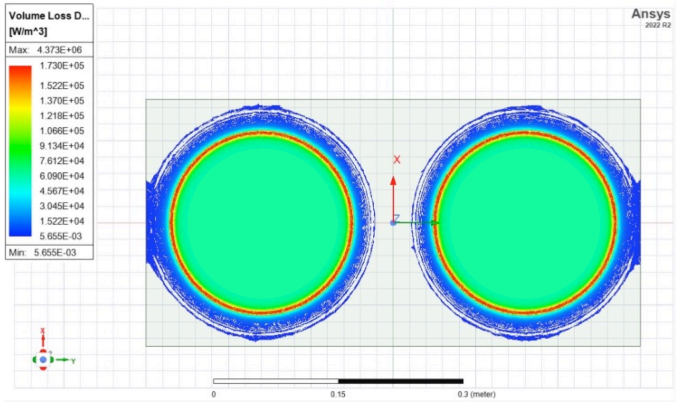

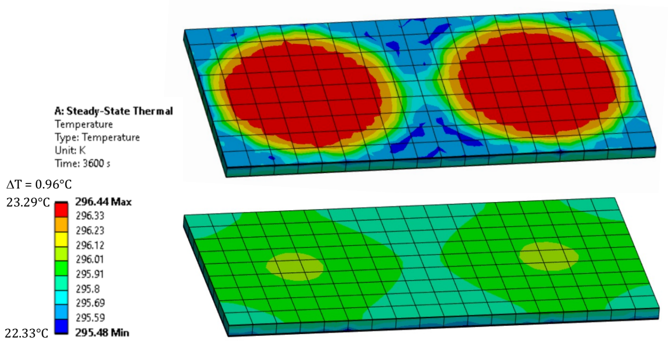

- Developing thermal models for asphalt and concrete pavement embedded capacitive and inductive wireless power transfer (WPT) systems
- Developed immittance network and transformer-based power combining architectures to enable power scaling of 6.78-MHz capacitive WPT system, achieving 6.2 kW at 81 kW/m² power transfer
- Capacitive WPT system has minimal losses in charging pads and most losses are in inverters, rectifiers and matching network inductors
- Used thermal imaging to collect thermal data from asphalt pavement test section with embedded inductive WPT at APT facility
- Conducted initial drone flights and collected sample thermal images of roadways to evaluate thermal performance of electrified roadways after receiving permissions from INDOT and FAA

Wireless Charging System Interoperability

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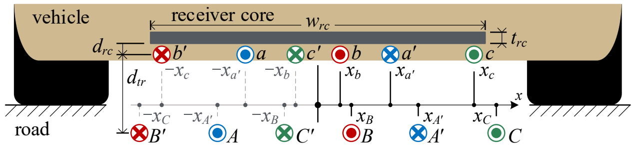
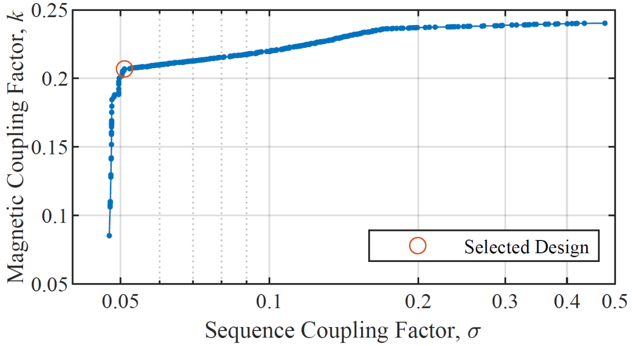
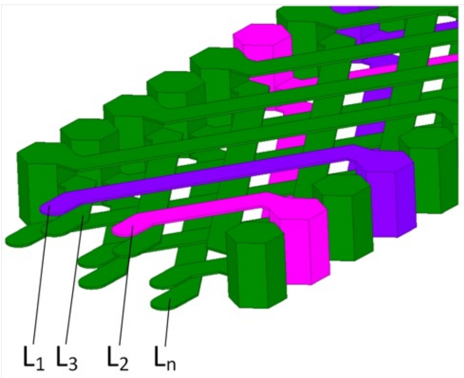
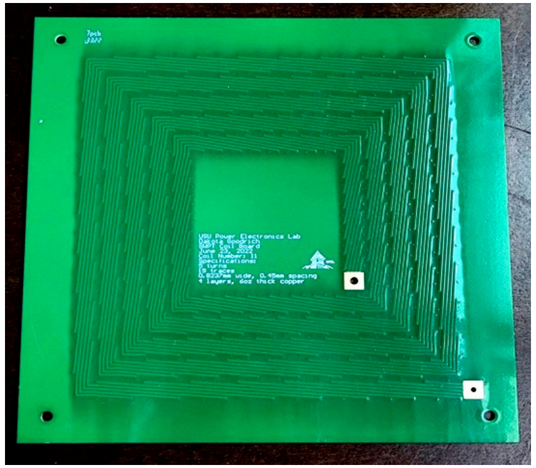
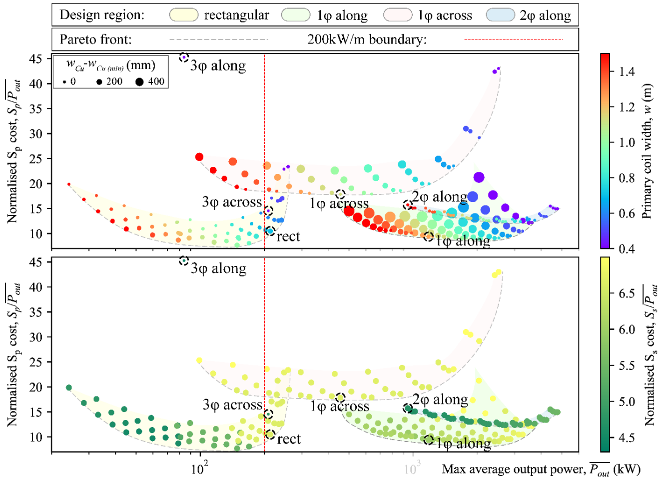
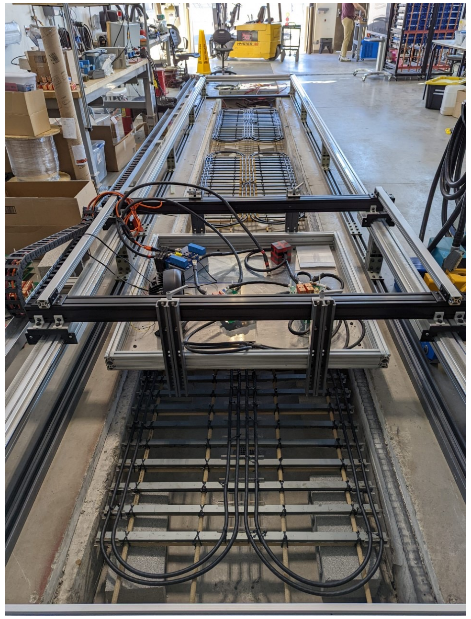






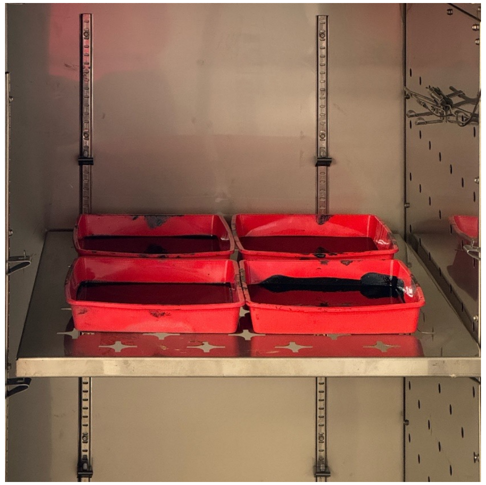


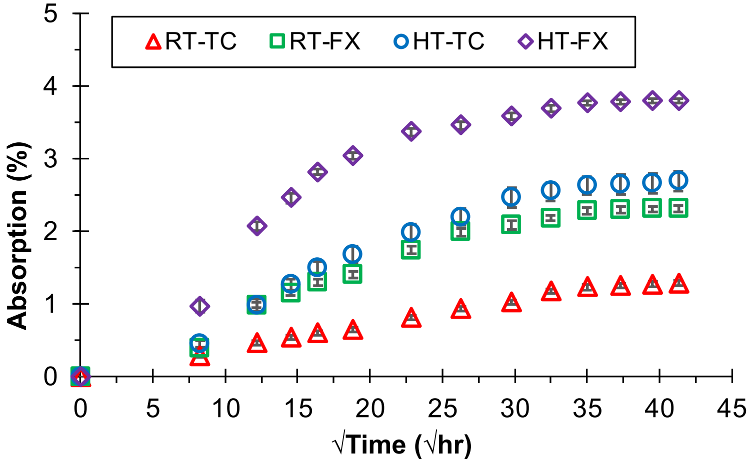


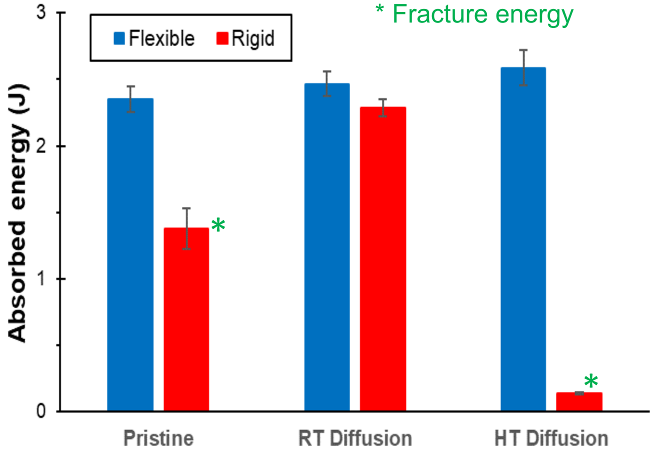


- Developing techniques to help design interoperable dynamic wireless power transfer (DWPT) systems — across vehicle classes, airgaps and power levels
- Developed approach to address whether transmitter and receiver of 3-phase inductive DWPT system needed to be co-designed — demonstrated different receivers can achieve good coupling factor and low sequence-coupling
- Evaluated ability of single- and multi-coil vehicle assemblies to operate with multiple classes of ground transmitter assemblies
- Developed fundamental techniques leveraging partial inductance to optimize performance of low-cost PCB-based Litz-coil geometries for vehicle assemblies
- Helped lead SAE J2954 standard development with focus on interoperability metrics

Embedded Electronics Packaging

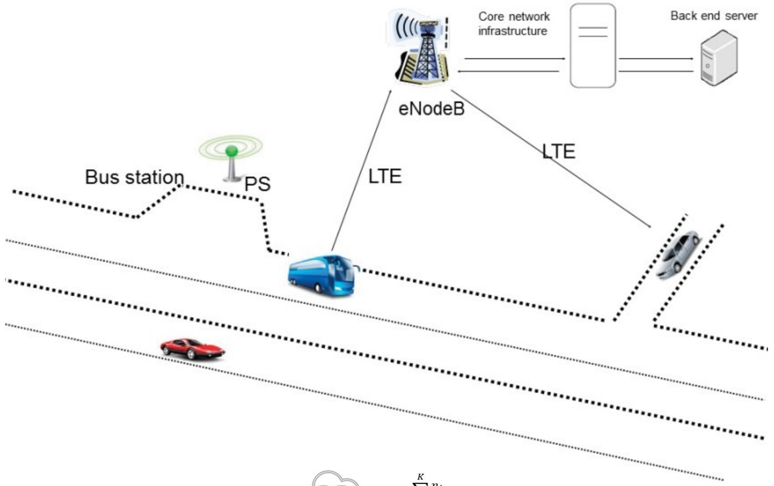


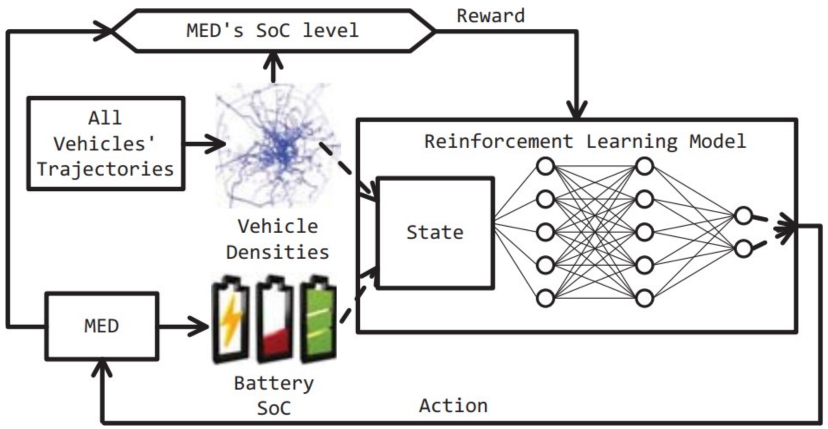


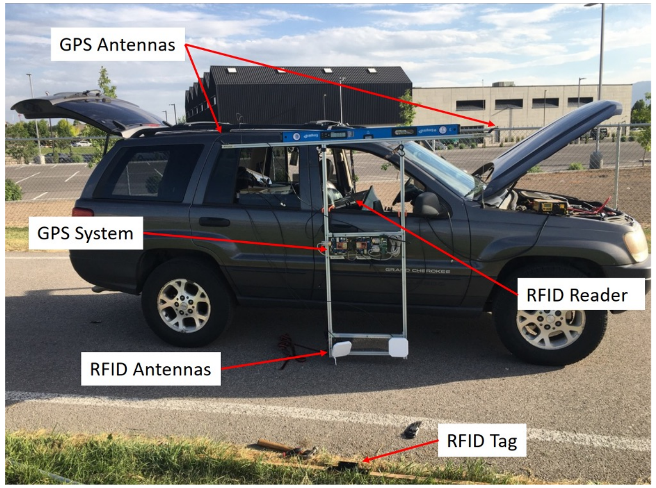


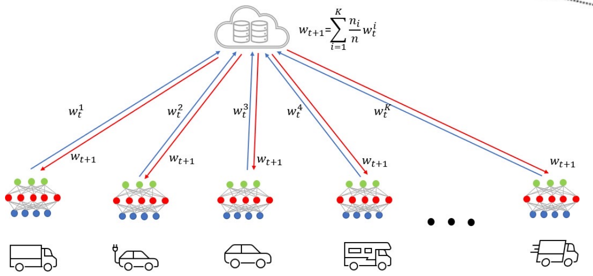
- Evaluating roadway embedded wireless charging components subjected to environmental loading, including water, temperature, and mechanical impact
- Evaluated performance of different epoxy materials as coatings for embedded components through water diffusion tests and low-velocity impact tests
- Identified flexible epoxy material as superior to rigid epoxy for embedded wireless charging applications, as it absorbs more energy during impacts and unlike rigid epoxy does not degrade mechanically under high temperature water diffusion
- Developed sequentially coupled finite element model to predict diffusion-induced damage followed by mechanical damage in electronics coated with an epoxy layer

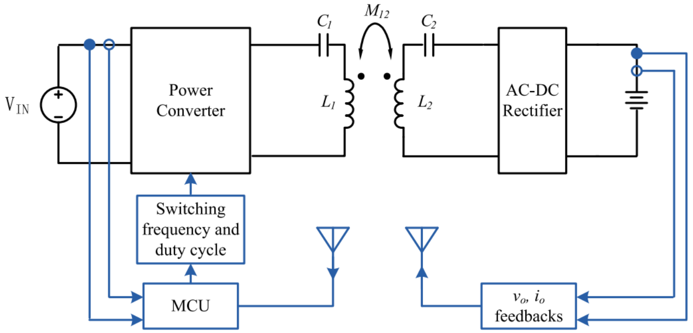
Secure Smart Electrified Roadways





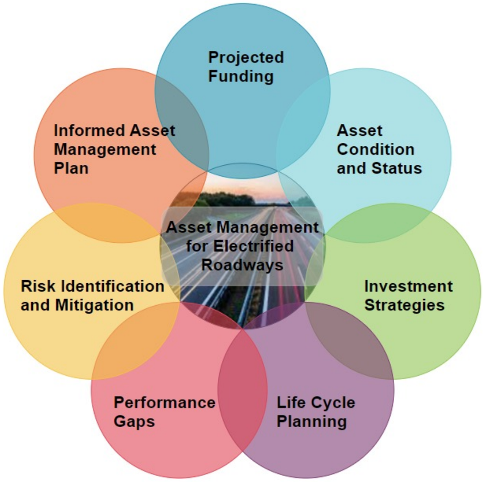






- Developing efficient, secure and low latency communication strategies for electrified roadways
- Tailored and optimized existing communication protocols, including dedicated short-range communications (DSRC) and cellular-vehicle-to-everything (C-V2X), to minimize infrastructure overhaul
- Experimentally evaluating DSRC and C-V2X communication through field tests utilizing commercial devices for vehicle and roadside units
- Employed RFID-based approach to align vehicles with electrified roadway wireless charging coils achieving centimeter-scale precision

Electrified Roadway Asset Management



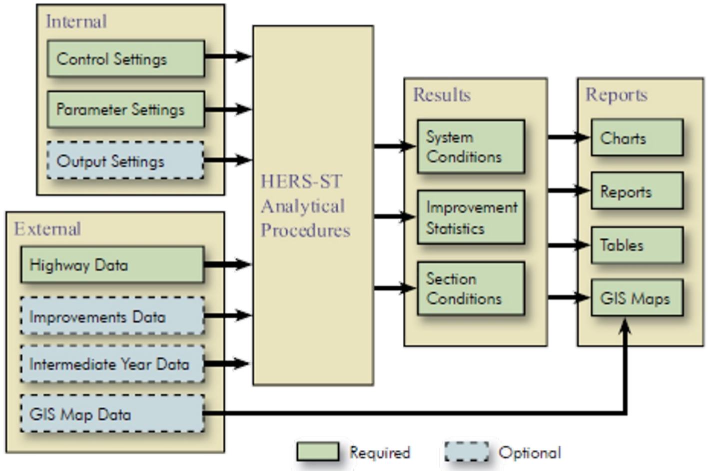
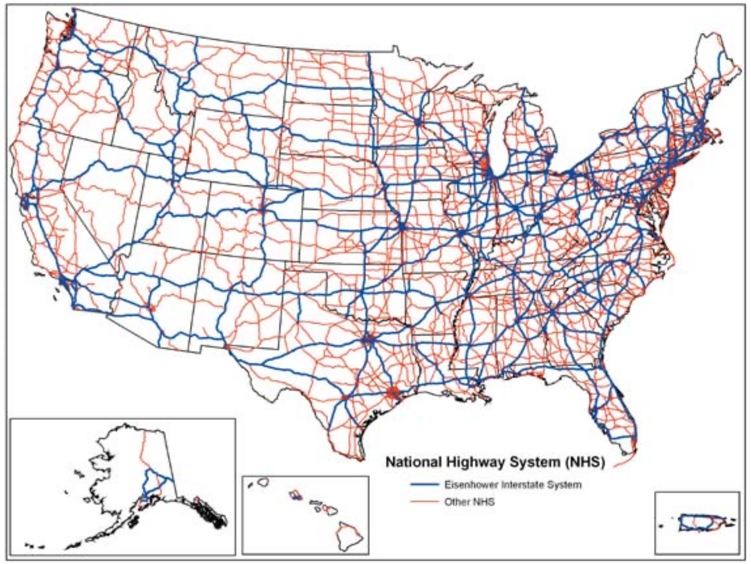


Figure 2-1. Overview of HERS-ST Process



- Developing transportation asset management (TAM) framework to evaluate economic and environmental benefits of electrified roadways
- Incorporated component and construction cost estimate data from industry partners for a one-mile segment of electrified roadway
- Incorporated risk and reliability factors to enable informed decision making in construction, operation and maintenance of electrified roads
- Developing risk management strategies that mitigate electrified roadway vulnerability to natural hazards and climate change events

INDOT Dynamic Wireless Charging Pilot

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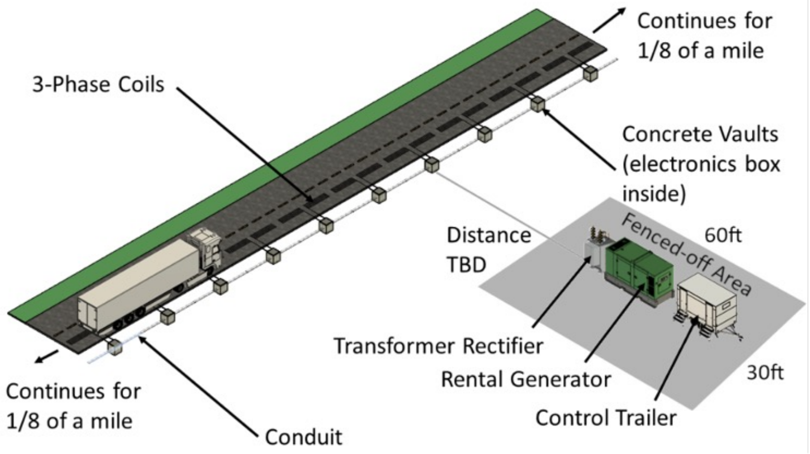

- Indiana Department of Transportation (INDOT) pilot electrifying ¼-mile segment of US 52/231 in West Lafayette
- Pilot utilizes inductive DWPT system designed by ASPIRE team
- Construction started in April 2024
- Transmitter coils assembled offsite utilizing rig for precise fabrication
- Channel milled in existing pavement for transmitter coil placement
- Boring done in pavement to provide electrical connection to roadway shoulder
- Power electronics to be placed in vaults in roadway shoulder

Engineering and Workforce Development

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- Electric Vehicle and Roadway (EVR) Open House for K-12 students & public
- Nerd Night events to encourage high school students to pursue STEM careers
- Small-scale demonstrations of in-motion wireless charging
- Media interviews highlighting wireless charging technology
- Easily accessible educational material related to electrified roadways
- Undergraduate students mentored through REU programs
- Industrial experience and professional skills through summer internships
- Graduate and undergraduate students presented papers at conferences
- ASPIRE-level course titled "Electrified Transportation Systems"
- Wireless Power School and Workshop as part of WPTCE 2024

Diversity & Culture of Inclusion

ASPIRE




- Active recruitment of faculty and students from underrepresented groups
- Active mentorship of students from underrepresented groups, including through involvement with Society of Women Engineers (SWE)
- ASPIRE Student Leadership Council (SLC) cohort program
- Native American Summer Mentoring Program (NASMP)
- Helped attract K-12 students from underrepresented groups towards STEM
- Course modules with DCI components
- Relationship development with underrepresented communities
- Understanding underrepresented community needs, priorities and aspirations

Summary

- Design of electrified roadways requires co-optimization of electrical, electromagnetic, thermal, structural, cyber-physical, and economic aspects of the system

- Year 4 focus on refining and experimentally validating models and tools for optimization, development and testing of prototype systems, and start of electrified roadway pilot

- Year 4 work has improved understanding of underlying fundamentals and resulted in promising component and system designs

- Year 5 will advance this work to help pave the way for more durable, maintainable, and cost-effective pavement structures with embedded wireless charging capability able to serve a wide range of vehicles

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Thank You!

Questions?

Panel Discussion

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The Path to National Scale Roadway Electrification

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Panel Questions

ASPIRE and INDOT are working together on the electrified roadway pilot in Indiana.

What are the goals of this project? What impacts do you expect it to have in the short- and longer-term?

Panel Questions

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How will success be defined for the ASPIRE-INDOT pilot? Assuming that it is successful, what would be the next step to enable electrified roadways to be rolled out more broadly in the state of Indiana?

Panel Questions

ASPIRE

Developing long-lasting pavements with embedded wireless charging technology would require novel solutions based on fundamental research.

What research have you been working on as part of Project 2: Electrified Roadways? What has been the most exciting part of this research?

Panel Questions

ASPIRE

The Indiana pilot is associated with the electrified roadway project, among others.

What are some of the other major objectives of Project 2? What activities are being pursued to achieve these objectives?

Panel Questions

ASPIRE

What have been some of the big technical challenges that you have encountered in the development of electrified roadways? What strategies or innovations have helped you overcome these?

Panel Questions

ASPIRE

What are the major barriers hindering widescale deployment of electrified roadways with wireless charging technology? What activities can ASPIRE, INDOT, and other Industry & Innovation members undertake to help overcome these barriers?

Panel Questions

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The electrified roadways project is highly multi-disciplanary across multiple campuses.

How has this collaboration across different fields and different campuses helped advance your research?

Panel Questions

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How can the benefits of electrified roadways with wireless charging technology reach underserved and marginalized communities, particularly those who might not be able to own expensive vehicles?

Panel Questions

Safety would be an important consideration in the design of electrified roadways.

What measures do you have to take to ensure the system is being deployed safely?

Panel Questions

The deployment of wireless charging technology on a national scale will require a skilled workforce.

What steps need to be taken to prepare the next generation of engineers for this emerging field?