Wireless Charging of Electric Vehicles in City Environment

Grand Challenge Proposal

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Section I: Project Idea.

Range anxiety *is the fear that a vehicle has insufficient range to reach its destination and would thus strand the vehicle's occupants (from Wikipedia, the free encyclopedia).*

One of the major obstacles to proliferation of electric vehicles (EV's) in cities is lack of infrastructure for charging of the EV's on-board batteries. Installation of numerous contact-type charging stations is impractical and poses a serious threat for public safety. A plausible solution seems to lie in a set of wireless power transmitters that send energy to wireless receivers installed in vehicles. The transmitters need to be embedded in streets and other city structures. The receivers are attached to vehicles. There have been recent demonstrations of an efficient wireless power transfer (WPT) for short distances (below 20 cm) or low powers (below 1 kW). City EV charging infrastructure requires, however, simultaneously distances of up to about 1 meter and power levels of about 10 kW.

This Grand Challenge proposal offers to develop technical solutions that will enable wireless charging of EV's both during parking (Phase I) and traffic (Phase II). It is expected that Phase I will last 2 years with an additional year to make the product commercial ready. A novel topology of a WPT system is proposed that comprises a PFC 60 Hz controlled rectifier, adjustable frequency resonant converter, wireless power link, and a high-frequency uncontrolled rectifier. Such a topology offers flexible control and high overall efficiency. The proposed solution will apply to the whole spectrum of vehicle types: from small passenger cars used by commuters, commercial passenger fleets of taxi and limo services, through small and medium utility and delivery trucks, to large buses and cargo trucks. A hypothetical view of parking charging stations in a city landscape is presented in Figure 1.

Figure 1. A hypothetical view of a charging station.

Three major technical challenges will be overcome. First, an air-core large-gap transformer will be designed to maximize the efficiency of the WPT. The transformer will use the principle of resonant magnetic coupling. The transformer primary, the transmitting coil, is embedded in the street. The transformer secondary, the receiving coil, is placed on the vehicle. This transformer structure need to posses the property of a high quality factor at any operating conditions: distance between coils, linear and angular misalignments, and size tolerances. The quality factor is defined as a ratio of the peak energy per switching cycle stored in the coil to the energy dissipated in the resonant circuit. The second major challenge is to design and build efficient high-frequency inverters that will power the transmitting coil. High-frequency operation offers higher efficiencies of power transfer at large distances between the transmitter and the receiver. The difficulty lies in neutralizing the effects of circuit parasitic components which increase with frequency and power levels. It is even more difficult when a wide range of operating frequencies is required due to a wide variety of powered vehicles. The third major obstacle is creation of a distributed control system that will efficiently use the available power resources. This control system will rely on wireless communication, networks of sensors, and distributed computations to provide real-time commands and information to customers and vehicles.

The completion of this project will bring many profound changes to city living: better health conditions through decreased pollution and noise level, improved traffic conditions through use of sensors and distributed control, and sociological effects of increased environmental awareness. From the economic point of view, this project is an important step towards the U.S.A. energy independence and will help to retain and create jobs in major American cities and their vicinities. Four main constituencies comprise the target market for the project's technology: EV manufacturers, municipal, public utility and commercial fleets. The size of the commercial market alone is estimated to be 18,000 vehicles in 2015 growing to 81,000 in 2018. Based on these projections, we size the market opportunity at ~$1.7bn. However, we believe this technology will provide significant upside to the entire transportation market.

Section II: Technical Approach and the Implementation Plan.

The block diagram of the proposed charging station is depicted in Figure 2.

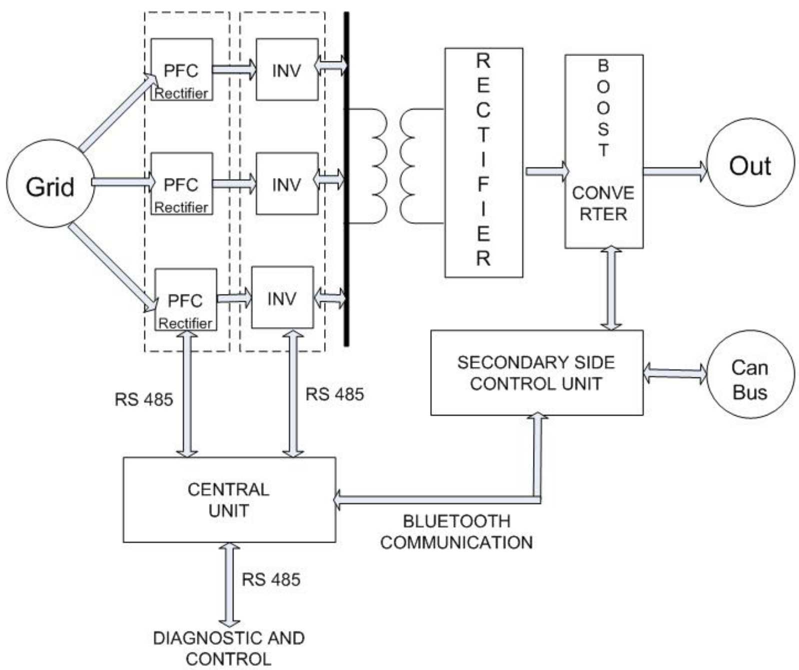


Figure 2. Block diagram of the proposed charging station.

The main activities associated with building the charging station are as follows:

- Design, build, and test a 12 kW controlled rectifier to convert AC power (60 Hz, 208 V) from the grid to a 0 to 300 V DC bus. The unit is marked by three 'PFC rectifier' boxes in Figure 2 because of 3-phase grid *ac* supply. The rectifier will perform the following functions:
    - o power factor correction (to meet IEEE 519)
    - o control *dc* output voltage according to the requirement of the battery charger
    - o wireless communication with the battery management system

This rectifier major technical challenge is to make the unit small and able to withstand stresses associated with the environment (mechanical, chemical, weather, etc.). A laboratory prototype of the PFC rectifier is currently being constructed by the proposing team. It is presented in Figure 3.

Figure 3. Laboratory prototype of a 3-phase PFC rectifier as constructed in NYU-Poly power laboratory.

- Design and build a 12 kW variable frequency resonant inverter of a few hundred kilohertz. This inverter will perform maximum power tracking.
  The idea of the inverter is based on magnetically coupled inductors with series resonating capacitors on both the primary and secondary sides. The schematic diagram of the circuit is shown in Figure 4. The primary side, which plays a role of a transmitter, is fed by a high-frequency *ac* source. The secondary side, a receiver, supplies a rectifier connected to the car battery system. The great challenge for the inverter is to operate simultaneously at high powers (for fast battery charging) and high frequencies (for high efficiency of the wireless link at distances of a few tens of centimeters). So far, the NYU-Poly team has achieved frequencies of 160 kHz at power levels of about 2 kW. It is expected that the switching frequencies need to be raised to about 700 kHz to achieve efficiencies above 85% at distances of 0.5 m between coils (inductors).

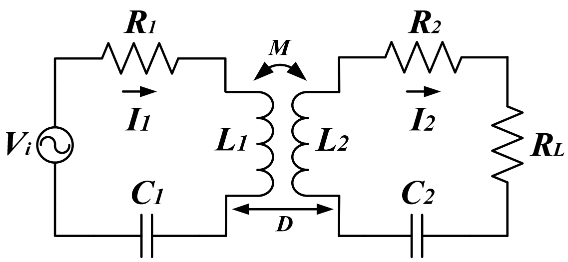


Figure 4. Series-series resonating magnetically coupled inductors.

- Design, build, and test a suitable resonant air-core transformer.
  For optimization of a resonant air-core transformer an accurate model is needed. NYU-Poly is developing models of such transformers in Maxwell3D and Simplorer packages. Figure 5 shows a 70 cm square-shaped primary coil of an air-core transformer. Figure 6 presents sample simulation results of a magnetic field distribution around a multilayer coil. Figure 7 presents a comparison between test and simulation results at about 100 W peak power level. It can be seen that further refinement of the model is needed.
- Design, build, and test a high efficiency uncontrolled rectifier to charge the battery. The battery charging will be adjusted by the controlled rectifier acting on the *dc* bus.
  The idea of an uncontrolled rectifier (RECTIFIER box in Figure 2) is to minimize size and weight of the electronics on the car.
- Integration and testing of the entire system to meet the required distance, efficiency and EMF emissions.
- Development of wireless sensor for optimal vehicle positioning.

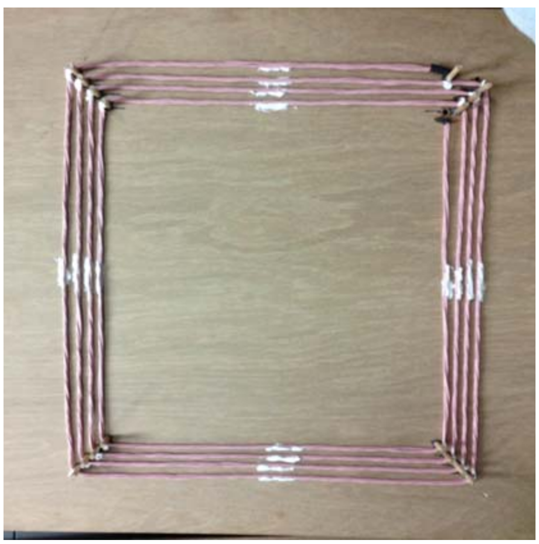


Figure 5. A square coil built in the power laboratory.

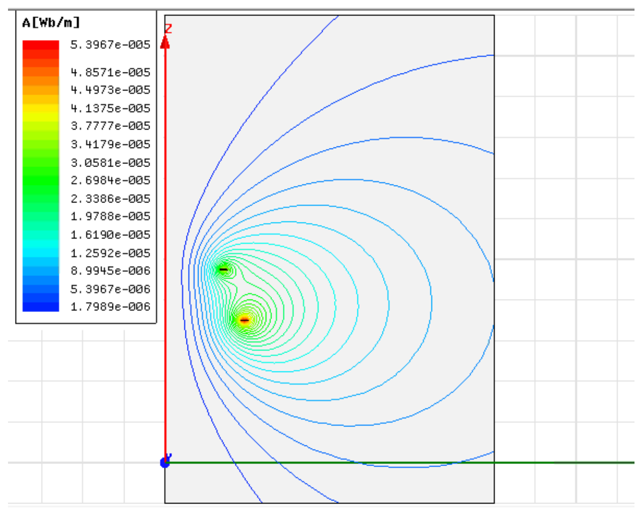


Figure 6. Simulation of magnetic field distribution in a multilayer coil.

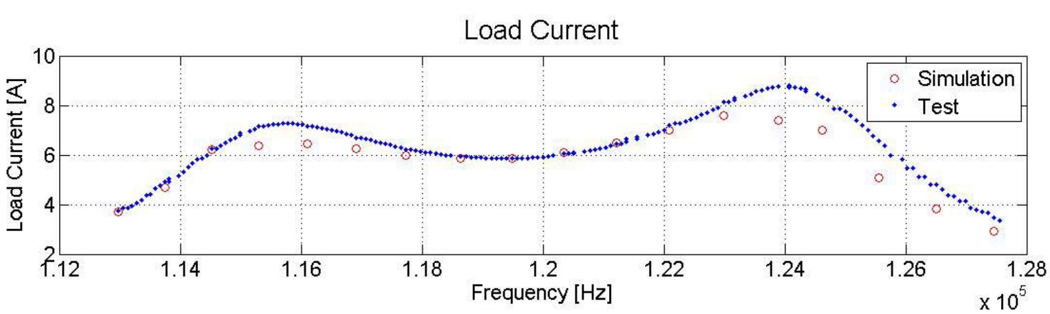


Figure 7. Test and simulation results for a WPT system with round coils at 26 cm.

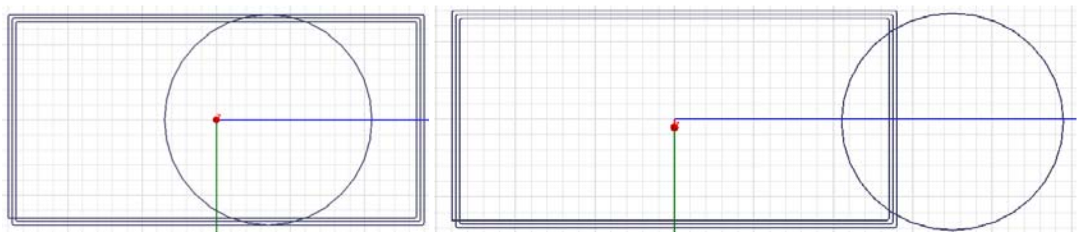


Figure 8. Shifting of a round receiver with respect to a rectangular transmitter.

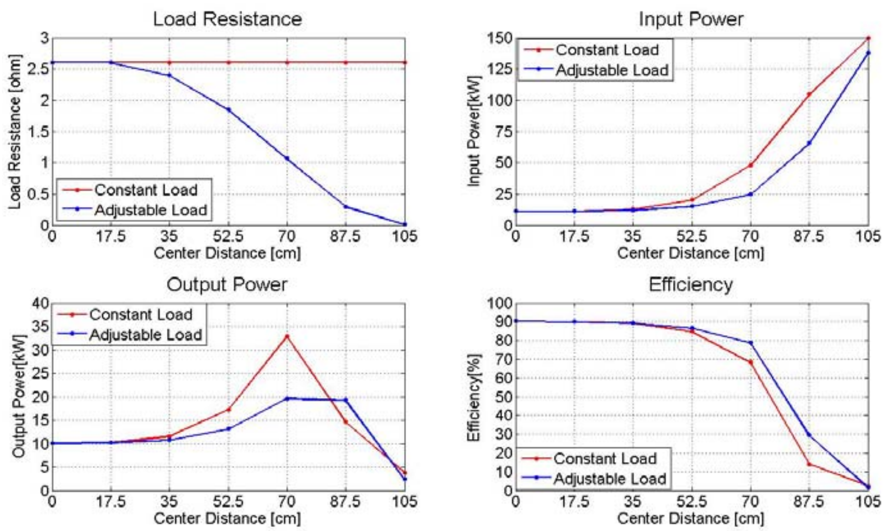


Figure 9. Simulation results for the coils in motion as per Figure 8.

The objective of Phase II is to enable EV charging during the vehicle participation in the city traffic. This should eliminate the need to stop an EV just for charging. A set of street-embedded WPT units will be developed to interact with passing vehicles. The interaction of each transmitter-receiver pair is only about 0.1 second which poses a significant challenge for efficiency and, hence, commercial feasibility of such a system. Some initial results for coils in motion obtained by the NYU-Poly team are presented in Figures 8 and 9. Phase II development period is about 5 years. Its major activities are:

- Modification of the resonant inverters and transmitters to make their operation compatible with a wide variety of WPT receivers. That could mechanical movement of the transmitter coil.
- Synchronization of WPT units wake-sleep regime in response to vehicle traffic
- Development and demonstration of an accurate CPS (City Positioning System, analogues to a GPS) for EV's. Such a system could be also used in the future for autonomous EV driving to ease traffic congestion.
- Optimization of location and size of WPT units along city streets based on traffic patterns.
- Integration of WPT systems with Con Edison and other utility systems.

The wireless charging ecosystem is at a nascent stage, with a handful of competitors in the space. Our industrial partner, HEVO, has a considerable advantage through its relationships, technology and mobile applications. Competitors such as Evatran, Qualcomm, and Wave are largely ignoring the commercial market and focusing instead on passenger vehicles. The OLEV project conducted in Korea by KAIST focuses on high-power specialty vehicles like trams that are matched to the underground charging system and operate at low frequency. The few

attempting to meet the needs of commercial vehicles such as Momentum Dynamics, are discounting the desire for mobile telematics, durability, convenience, easy maintenance and ubiquitous use by any vehicle.
Ultimately, our units will offer higher charging rates than competitors with greater efficiency metrics at a lower operational cost. HEVO is also the only company in the industry that offers a mobile platform that connects our technology with services in a seamless, simple-to-use environment.

The main activities associated with commercial application of the charging station for Phase I and II are as follows:

- Establish partnerships with principal commercial electric vehicle Original Equipment Manufacturers (OEMs).
  Technical information sharing streamlines the integration and compatibility of our technology with the entities that will comprise a subset of initial customers and advocate for the use of our technology. To date, the team has secured relationships and initiated information sharing with three OEMs– Smith Electric, e-Ride and Zero Truck. The team continues to engage other commercial EV OEMs and will lay the groundwork for partnerships with passenger EV OEMs.

- Demonstrate the technology with municipalities, utilititis, manufacturers and fleets in CA, MN and NY in a real-world setting.
  The research objectives outlined in this proposal will allow the team to pursue real world demonstrations with its partners in order to validate the scalability and repeatability of its business model. Management is keenly aware that the development of a new product requires an iterative process of product and customer validation. Therefore, one important steps is to test the prototypes to ensure that the end product conforms to the actual needs of its customer base and that all necessary steps have been taken to prepare for production. Both lab and real world demonstrations will also be used to showcase the product to key commercial, municipal and federal stakeholders to showcase its viability. The development team has secured commitment for demonstration with three commercial EV OEMs and has expressed interest from key stakeholders among utilities and municipalities in CA and NY. Figure 10 details the business model validation process.

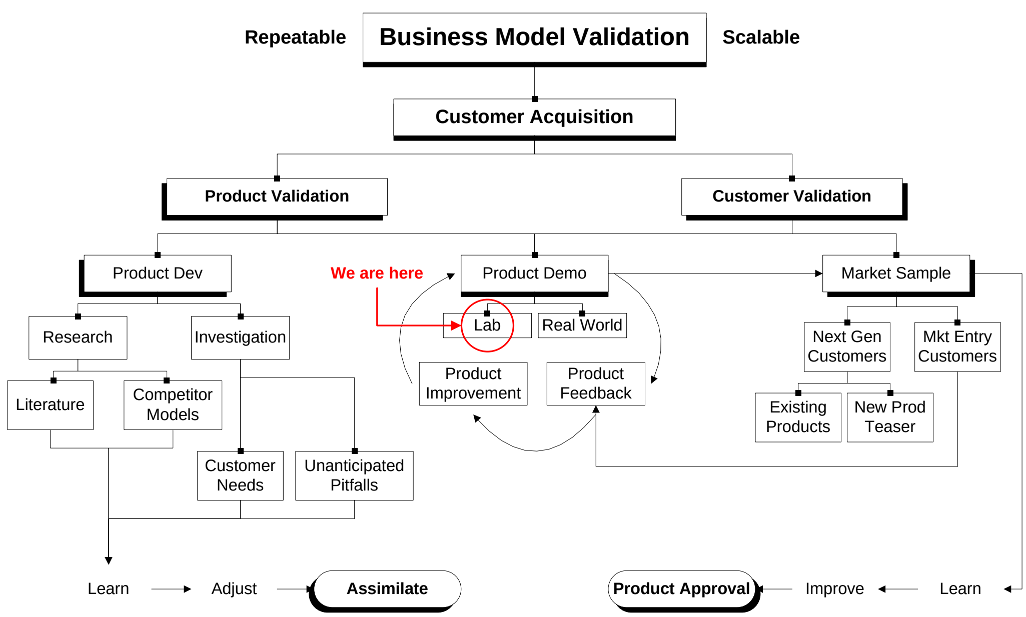


Figure 10. Business Model Validation

- Initiate production methodology and supply chain support
  Our industrial partner has articulated its own production methodology and undergone reverse planning to identify the workstreams and milestones necessary to reach initial production of its first generation units. Workstreams include, but are not limited to: the investigation of contractual, warranty and licensing parameters with development and distribution partners Smith Electric Vehicles and Milea Trucking Sales to name a few; customer relationship management processes; expansion of terms of service with additional distributors; purchase order acquisition; installation training; production facility determination and materials acquisition and all necessary follow on operations. The team will continue to collaborate with its composite manhole cover manufacturer partner, Fibrelite, to encase the raw units in a durable and deployable unit suitable for real-world application. Sourcing analysis and operations process analysis will be initiated by the internal team. In preparation for full-scale manufacturing, consulting will be sourced through our industrial design engineer contractors MakeSimply. The diagram shown in Figure 11 represents the production methodology and process flow to reach production.

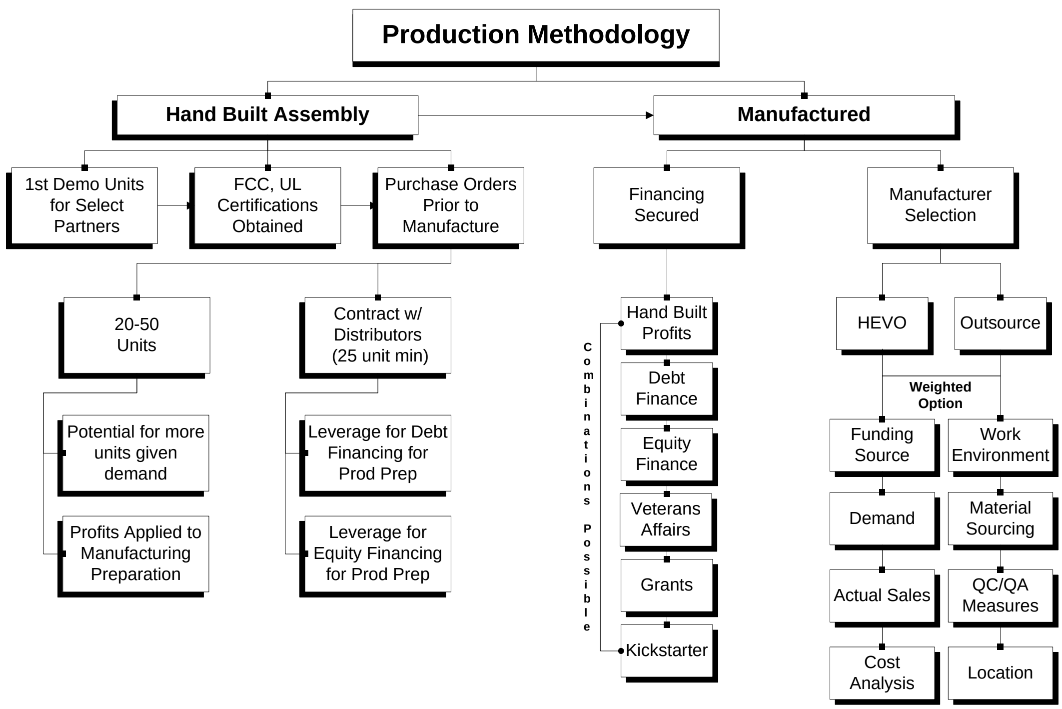


Figure 11. Business Model Validation

- Secure demand chain support
  Demand chain support will initiate with distribution partners supported by HEVO engineers with real time access to embedded sensory software output that relays parameter and threshold alarms in order to streamline repairs and service of pilot units. Outbound logistics will be determined and managed by Crystal Ball decision modeling.

- Conduct feasibility analysis of public curbside charging for commercial EVs
  We have received expressed commercial interest from the corporate offices of Duane Reade and other high profile companies who have stated their desire and need for an EV charging infrastructure in New York City and CA. To that point, our industrial partners recently received a NYSERDA reward to conduct a feasibility study with the New York City Department of Transportation in order to investigate the

implementation of wireless power and GLZs. The feasibility study is the first step towards the investigation and testing of Green Loading Zones in New York City, which could accelerate the entry into the sustainable infrastructure market.

- Identify legal parameters for public wireless charging
  Land use and zoning laws challenge public use for both static and dynamic applications of wireless charging, however, existing embedded roadway sensory technology and fuel line permitting set precedents for these applications. The business team will continue to explore relationships and strategic implementation of public wireless charging through its legal offices.

Section III: Milestones and Metrics of Success.

There are several critical technology and business development milestones to bring the city wireless charging stations to market. Successful product demonstration in a real world environment is the key to confirming and meeting customer needs and is emblematic of the customer focus driven commercialization strategy employed by our industrial partner HEVO. Two methods of customer acquisition will drive the commercialization strategy and revenue model: 1) wholesale of wireless power units and wireless receivers to regional distributors, which are then retailed to companies demanding wireless power for their commercial fleets and loading yards; and 2) to ubiquitously provide wireless power as sustainable urban infrastructure in permitted areas called Green Loading Zones (GLZ). Municipalities in metropolises like New York City, Chicago and San Francisco have been actively recruiting commercially focused companies offering Electric Vehicle Supply Equipment (EVSE) in order to establish these zones.

The following list outlines the key milestones and schedule that lead to the sale and installation of the first generation units to commercial clients in NYC, CA and MN in May of 2014 for Phase I and the scaling strategy for Phase II.

Phase I

- At 5 months: Alpha I Unit Encased in Enclosure
  A raw 3.3 kW transmitter and receiver unit will be encased in durable fiberglass composite shell. Minimum 1; Maximum 3
- At 6 months: Embeddable Alpha I Unit Lab Demo
  Confirm functionality of raw unit within enclosure. Output current = 27.5 amps; output voltage = 120V; output power = 3.3 kW; thermal monitoring sufficient to dissipate 90 degrees Celsius; telematics monitoring of percentage charged and kWs transferred per charging incident; parking optimization integration with audio and visual cues.
- At 8 months: Alpha I Pilot Demos – NYU-Poly and HEVO Pathfinder Launch Program
  Demonstrate functionality with Commercial EV Manufacturer in private yards. One demonstration each is to take place in Minneapolis, NYC and Santa Monica.
- At 9 months: Alpha I Showcase Demo
  Demonstrate functionality at venues such as Cleantech Open Midwest Conference investor and press event.
- At 12 months: Obtain Purchase Orders
  Secure purchase orders for Gen I product launch. Minimum 30; Maximum 100
- At 14 months: Alpha II Pilot Demos
  Upgrade 3 existing demo units in the field with expanded mobile telematics package
- At 15 months: FCC/UL/NEC Certifications Filed
  Ensure Gen I units meet necessary FCC, UL2231, UL1998, UL991 and NEC625 certifications
- At 16 months: Production Facility & Materials Secured
  Obtain capacity & materials needs sufficient for 100 unit manufacture of Gen I units over 3 months
- At 18 months: Installation Training Initiated

Draft materials and specs for use by qualified installation partners & internal engineers - one installation guide and installation video.

- At 24 months: Production Initiated

  Development, supply and demand chain operational processes sufficient for 100 unit production over 3 months

Phase II

Phase II milestones and dates are contingent upon successful completion of Phase I.

- Expand penetration of the NYU-Poly and HEVO Pathfinder Launch Program with utilities, manufacturers, municipalities and fleets
- Demonstrate higher charge rates of 10 kW at a minimum and ability of a single wireless power unit to charge multiple vehicle makes and models
- Increase functionality of telematics for wireless bill pay, mobile advertising, and gamification
- Identify and secure manufacturing needs based on existing penetration
- Initiate execution of curbside public charging for commercial electric vehicles
- Identify legal parameters and barriers to dynamic charging
- Incorporate customer feedback for functionality and design elements for Gen II product
- Establish pilot demonstrations for Gen II product in both private and public applications as Green Loading Zones
- Expand EV OEM relationships to passenger EVs

Commercial Vision during beyond Phase I & II

The proposed wireless charging network will provide cost and operational solutions for commercial fleets in urban areas. Commercial fleet operators face high transportation costs, range anxiety, and the inconveniences of plug-in fuel stations (diesel and electric). NYU-Poly and HEVO will lead the market by providing a hands-free, hassle-free experience for fleet operators which will allow them to manage their distribution routes and cost structure more efficiently. We will position our products, the Charging Station, Wireless Receiver and Mobile app as a top quality wireless charging ecosystem providing the customers with exceptional value to be the market standard charging technology in the future.

Section IV: External Partners and the Community.

The success of the project will require participation of other experts and business entities. In particular, material science, civil engineering, and mechanical engineering experts from NYU-Poly will be involved. NYU Medical School will perform studies on health effects of long time exposure to magnetic fields in the 0.1 – 1 MHz frequency range. Major business partner will be HEVO Inc., a company located in the NYU Varick Street incubator whose business model is based on wireless EV charging. Through HEVO, the team will cooperate with the end users of the technology such as the City of New York, commercial EV manufacturer Smith Newton, city EV fleet operators (Fresh Direct, Duane Reade, etc.), and passenger car manufacturers (Nissan, GM, Ford, etc.).

The list below gives examples of companies and other entities that will be a part of this project. Many of them have been already contacted by the team members.

- **Supply Side Support** - design, sourcing, inbound logistics and production/operations value activities: *Fibrelite* –manufacturer that will encase the hardware in a rugged 25,000 PSI fiberglass composite manhole cover; *MakeSimply* – industrial design and manufacture for economies of scale and scope.
- **Commercial EV Original Equipment Manufacturers (OEMs)** – integration, compatibility, pilot demonstration, and customer acquisition: *Smith Electric Vehicles*; *Zero Truck; e-Ride, Motiv Power Systems; Via Motors*.

- **Utilities** – permitting and grid management: *Con Edison*; *PG&E* .
- **Municipalities** – advocacy, education, demonstration and customer acquisition: *NYC DOT; San Francisco Department of the Environment*; *City of Santa Monica*.
- **Commercial Fleets** – for demonstration and customer acquisition: *Duane Reade*; *Fresh Direct.*
- **Distribution Partners** – wholesale customer and installation/service partner: *Milea Truck Sales*.
- **Government & Public Advocacy** – lobbying and consumer education: *Barretto Bay Strategies; University Transportation Research Center*; *Bay Area Climate Collaborative*.
- **Urban Architecture** – identification of public charging design parameters consistent regulations: *WXY + Architecture.*
- **Legal Services** – intellectual property rights and identification of legal parameters for public charging: *RoyLance Abrams*; *Latham Watkins*.
- **IT Services** – front and back-end support for mobile telematics: *ScriptBlue*; *Circles iO*.

The seed funding will be used during the first two years of the project to support NYU-Poly PhD and MSc students and provide for long term visits of researchers from other leading WPT institutions such as Wuhan University, PR China, and Korea Advanced Institute of Science and Technology, South Korea. Funds are also needed for materials and supplies since the most advanced components must be used to achieve high power conversion efficiencies. Finally, specialized power and wireless equipment and instrumentation as well as licenses for advanced software will be needed. Subsequent years of the project will be funded through governmental and private company grants and projects.

APPENDICES

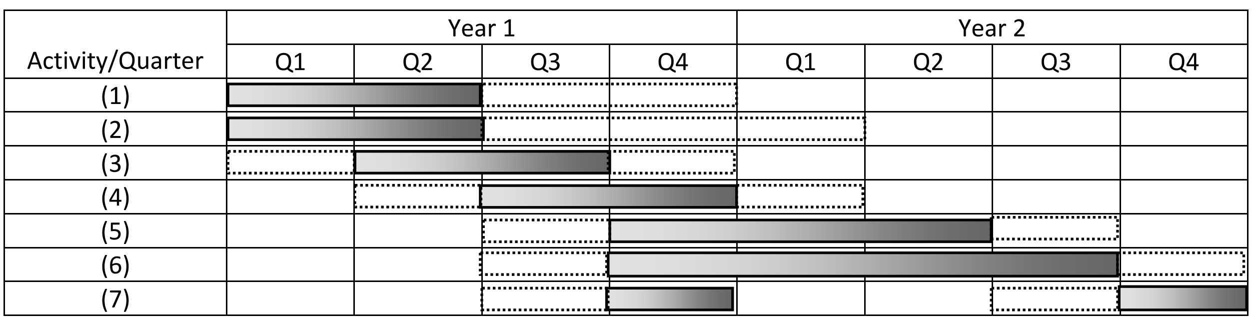
Management and Staffing Plan

PI's and Key Personnel Experience

Associate Professors Czarkowski and de Leon have been managing numerous externally funded research projects. Their support comes from federal, state, and industry sources and averages several hundreds of thousands of dollars per year. Prof. de Leon has been awarded by DOE a 2 million dollar grant on toroidal transformers. Drs. Czarkowski and de Leon supervised several postdocs, graduated more than 20 PhD students, and supervised numerous MS theses and student projects. Prof. Czarkowski will supervise project activities related to power electronics such as the development of novel high-power high-frequency inverters. Prof. de Leon will manage activities on transmitter and receiver design and optimization. Industry Professor Mike Knox, in addition to full-time teaching and research duties at NYU-Poly, brings 30 years of industrial experience. He has founded and served as President/CEO of 2 companies. Prof. Knox will supervise technical parts of the project concerned with sensors and wireless communication.

J. McCool and S. Monks are founders, and CEO and COO, respectively, of HEVO Inc., an NYU-Poly incubator company. They both hold MPA degrees from Columbia University School of International and Public Affairs. They will be responsible for commercialization efforts of the project.

Project Schedule



(1) Design, build, and test the input 12 kW controlled rectifier
(2) Design and build a 12 kW variable frequency resonant inverter
(3) Design, build, and test the resonant air-core transformer
(4) Design, build, and test the uncontrolled rectifier to charge the battery
(5) Integration and testing of the entire system to meet the required distance, efficiency and EMF emissions
(6) Development of wireless sensor for optimal vehicle positioning
(7) Writing reports, patents, and papers

Management

To measure the progress of the project the team will meet once a week for the duration of the project. In the meetings, each member will present the progress made during the previous week. Ideas and obstacles will be discussed in the team looking for possible solutions always supervised by the faculty PIs. This strategy to manage the project promotes teaching, training and learning. Individuals at various levels of technical expertise interact with each other to solve a common problem. For example, an advanced PhD student will face an interesting challenge when trying to explain a highly technical concept to an undergraduate student. Both will benefit from the interaction.

Staffing Plan

The students that will serve as researchers and developers in this project (PhD and MSc students) will be selected from the pool of students already enrolled in our program and that we have already evaluated ourselves in class and research work. These students will be selected because of their proven production with us. Other students, for example Graduate Assistants (GAs) and undergraduate Design Projects will be selected based in their perceived potential to learn and produce with the aim of eventually substitute the PhD and MSc as the researchers.

BIOGRAPHIES

Dariusz Czarkowski
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Professional Preparation:

M.S. in Electronics Engineering, AGH University of Science and Technology, Cracow, Poland, 1988.
M.S. in Electrical Engineering, AGH University of Science and Technology, Cracow, Poland, 1989.
M.S. in Electrical Engineering, Wright State University, Dayton, OH, 1993.
PhD in Electrical Engineering, University of Florida, Gainesville, FL, 1996.

Appointments:

2002-present Associate Professor, Polytechnic Institute of NYU (formerly known as Polytechnic University)
1996-2002 Assistant Professor, Polytechnic University, Brooklyn, NY.
1994-1996 Research Assistant, University of Florida, Gainesville, FL.
1993 Adjunct faculty member, Wright State University, Dayton, OH.
1991-1993 Research Assistant, Wright State University, Dayton, OH.
1990-1991 Instructor, University of Mining and Metallurgy, Cracow, Poland.
1989-1990 Software engineer, Moszczenica Coal Mining Company, Jastrzębie Zdrój, Poland.

Selected Products Related to the Proposed Project:

1. M. K. Kazimierczuk and D. Czarkowski, *Resonant Power Converters, 2nd ed.*, New York: Wiley Interscience, 2011.
2. D. Czarkowski, "Series-Resonant Inverters", chapter in *The Power Electronics Handbook*, edited by Timothy L. Skvarenina, CRC Press, 2002.
3. S. Zheng and D. Czarkowski, "High-voltage high-power resonant converter for electrostatic precipitators," *IEEE Transactions on Industrial Electronics*, vol. 54, pp. 707-715, April 2007.
4. D. Czarkowski, D. Chudnovsky, G. Chudnovsky, and I. Selesnick, "Solving the Optimal PWM Problem for Single-Phase Inverters," *IEEE Trans. on Circuits and Systems*, vol. 49, no. 4, pp. 465-475, April 2002.
5. D. Czarkowski and M. K. Kazimierczuk, "Single–capacitor phase–controlled series resonant converter," *IEEE Trans. Circuits Syst.*, vol. CAS-40, pp. 383-391, June 1993.

Other Significant Products:

1. D. Czarkowski, "DC-DC Converters", chapter in *Power Electronics Handbook, 3rd ed.*, edited by Muhammad H. Rashid, Academic Press, 2010.
2. L. Yu, D. Czarkowski, and F. de León, "Optimal Distributed Control for Voltage Regulation of Distribution Systems with Distributed Generation Resources", *IEEE Transactions on Smart Grid*, Vol. 3, No. 2, June 2012, pp. 959-967.
3. L. Li, D. Czarkowski, Y. Liu, and P. Pillay, "Multilevel selective harmonic elimination PWM technique in series-connected voltage inverters," *IEEE Trans. on Industry Applications*, vol. 36, no. 1, pp. 160-170, Jan./Feb. 2000.

4. D. Czarkowski and M. K. Kazimierczuk, "ZVS Class D series resonant inverter – discrete-time state-space simulation and experimental results," *IEEE Trans. on Circuits and Systems*, vol. 45, no. 11, pp. 1141-1147, Nov. 1998.

5. D. Czarkowski, L. R. Pujara, and M. K. Kazimierczuk, "Robust stability of state-feedback control of PWM dc-dc push-pull converter," *IEEE Trans. Industrial Electronics*, vol. IE-42, pp. 108-111, Feb. 1995.

Synergistic Activities:

Associate Editor for *International Journal of Power and Energy Systems.*
Advisor to junior udergraduates under the NSF REU program (12 students over 8 years).
Supervisor of high school students for the Poly YES program (10 students over 4 years).
Panelist for NSF SBIR program.
Reviewer for several *IEEE Transactions*, *IEE Proceedings*, and other journals.
Consultant for industry.

Collaborators and Co-Editors:

Dr. A. Ioinovici, Holon Institute of Technology, Israel.
Dr. D. Chudnovsky, Polytechnic Institute of NYU.
Dr. G. Chudnovsky, Polytechnic Institute of NYU.
Dr. A. Domijan, Jr., University of Florida.
Dr. E. Erkip, Polytechnic Institute of NYU.
Dr. D. Goodman, Polytechnic Institute of NYU.
Dr. R. Karri, Polytechnic Institute of NYU.
Dr. M. K. Kazimierczuk, Wright State University.
Dr. F. de Leon, Polytechnic Institute of NYU.
Dr. N. Mohan, University of Minnesota.
Dr. P. Pillay, Clarkson University.
Dr. M. Rashid, Florida State University.
Dr. I. Selesnick, Polytechnic Institute of NYU.
Dr. Y. Wang, Polytechnic Institute of NYU.
Dr. Z. Zabar, Polytechnic Institute of NYU.

Graduate Advisors and Postdoctoral Sponsors:

Graduate Advisor, Dr. Marian K. Kazimierczuk, Wright State University.
Graduate Advisor, Dr. Alex Domijan, Jr., University of Florida.

Thesis Advisor and Postgraduate-Scholar Sponsor:

J. Biernacki, Polytechnic Institute of NYU
W. Bury, DeVry Institute
L. Li, Pico Electronics
P. A. Novak, Otis Elevators
D. Shmilovitz, Tel-Aviv University
T. Sulawa, mPower
J. Sun, Polytechnic University
V. Spitsa, Polytechnic Instituite of NYU
R. Uosef, Consolidated Edison of New York
D. Wang, Tesla Motors
Q. Tang, Fairchild Semiconductor
L. Yu, Consolidated Edison of New York

Francisco de Leon, Ph.D.

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Research Areas

My areas of greater teaching and research interest include the transient and steady-state analyses of electrical power systems, the analysis of power definitions under nonsinusoidal conditions, the thermal rating of cables and transformers, and the calculation of electromagnetic fields applied to machine design and modeling.

Education

Ph.D. in Electrical Engineering from the University of Toronto, Canada 1992
M.Sc. in Electrical Engineering from the National Polytechnic Institute, Mexico 1986
B.Sc. in Electrical Engineering from the National Polytechnic Institute, Mexico, 1983

Post-Doctoral Studies

University of Toronto, September 1998 to March 1999.
McGill University, September 1997 to August 1998.
University of Toronto, January to September 1992.

Productivity

I have over 100 publications (46 journal papers, 3 power engineering letters plus 14 discussions in the IEEE Transactions, 40 conference papers, and a few other publications). My papers have been cited over 300 times in journals listed in the Science Citation Index and over 750 times in Google Scholar. I have made 4 patents applications and have graduated 3 Ph.D., 20 M.Sc. and many B.Sc. students.

Professional Experience

Polytechnic Institute of NYU - Associate professor. From September 2007 to date.
CYME International - Director of R&D. From 2004 to 2007.
Universidad Michoacana - Titular Professor. September 2001 to December 2003.
Plitron Manufacturing Inc. R&D Engineer. From September 1999 to August 2001.
Windomotion - R&D Engineer. From April to August 1999.
National Polytechnic Institute of Mexico - September 1992 to August 1997.

Five Publications Related to the Project

1) **F. de León**, S. Purushothaman, and L. Qaseer, "*Leakage Inductance Design of Toroidal Transformers by Sector Winding*", to be published in the IEEE Transactions on Power Electronics in October 2013.

2) S. Jazebi, **F. de León**, and B. Vahidi, "*Duality-Synthesized Circuit for Eddy Current Effects in Transformer Windings*", IEEE Transactions on Power Delivery, Vol. 28, No. 4, April 2013, pp. 1063-1072.

3) L. Qaseer, S. Purushothaman, and **F. de León**, "*Closed-Form Analysis of Squirrel-Cage Induction Motors With Anisotropic Modeling of Stator and Rotor*", IEEE Transactions on Energy Conversion, Vol. 27, No. 3, pp. 553-560, September 2012.

4) C. Álvarez-Mariño, **F. de León**, and X. M. López-Fernández, "*Equivalent Circuit for the Leakage Inductance of Multi-Winding Transformers: Unification of Terminal and Duality Models*", IEEE Transactions on Power Delivery, Vol. 27, No. 1, January 2012, pp. 353-361.

5) I. Hernández, **F. de León**, and P. Gómez, "*Design Formulas for the Leakage Inductance of Toroidal Distribution Transformers",* IEEE Transactions on Power Delivery, Vol. 26, No. 4, October 2011, pp. 2197-2204.

Five Other Publications

6) P. Gómez and **F. de León**, "*Accurate and Efficient Computation of the Inductance Matrix of Transformer Windings for the Simulation of Very Fast Transients*", IEEE Transactions on Power Delivery, Vol. 26, No. 3, July 2011, pp. 1423-1431.

7) P. Gómez, **F. de León**, and I. Hernández*, "*Impulse Response Analysis of Toroidal Core Distribution Transformers for Dielectric Design*", IEEE Transactions on Power Delivery, Vol. 26, No. 2, April 2011, pp. 1231-1238.

8) **F. de León** and J. Cohen, "*AC Power Theory from Poynting Theorem: Accurate Identification of Instantaneous Power Components in Nonlinear Switched Circuits*", IEEE Transactions on Power Delivery, Vol. 25, No. 4, October 2010, pp. 2104-2112.

9) **F. de León** and J. A. Martinez, "*Dual Three-Winding Transformer Equivalent Circuit Matching Leakage Measurements*", IEEE Transactions on Power Delivery, Vol. 24, No. 1, January 2009, pp. 160-168.

10) **F. de León** and G. Anders, "*Effects of Backfilling on Cable Ampacity Analyzed with the Finite Element Method*", IEEE Transactions on Power Delivery, Vol. 23, No. 2, April 2008, pp. 537-543.

Patents

1. D. Wang, D. Czarkowski, **F. de Leon**, K. Kamiar, L. Gao, and S. Liu, "*System and Methods for High Power DC/DC Converter*", Pub. No.: US 2013/0083563 A1, Ap. 4, 2013.
2. Q. Tang, D. Gu, D. Czarkowski, **F. de Leon**, K. Karimi, and S. Liu, "*Apparatus and Method for Controlling Circulating Current on an Inverter System*", Jan 2012.
3. Q. Tang, D. Czarkowski, **F. de Leon**, K. Karimi, and S. Liu, "*Power System Having Repetitive Control in Symmetric Sequences with Harmonics Cancellation*", Jan 2012.
4. K. Karimi, S. Liu, D. Czarkowski, **F. de Leon**, K. Colak, D. Gu, Q. Tang, D. Wang, and M. Bojarski, *"Aircraft Universal Power Converter for Fuel Cell Integration"*, 2012.

Synergistic Activities

- **Editor.** IEEE Transactions on Power Delivery, July 2009 to date.
- **Editor/Coordinator**. IEEE Power Engineering Letters, 2009 to date.
- Reviewer. IEEE Transactions on Power Delivery, 1992 to date.
- Reviewer. European Transactions on Electric Power, 2007 to date.
- Reviewer. International Journal of Power and Energy Systems, 2008.
- Reviewer. IET Electric Power Applications, 2009 to date.
- Reviewer. International Journal of Emerging Electric Power Systems, 2009 to date.
- Reviewer. IEEE Power and Energy Society Letters, 2007 to date.
- Reviewer. Taylor & Francis Electric Power Components and Systems, 2009 to date.
- Reviewer for DOE's Smart Grid Investment Grant Program, 2009.

Michael Knox, Ph.D.

mikeknox@poly.edu

PROFESSIONAL EXPERIENCE

Polytechnic Institute of NYU, Department of Electrical and Computer Engineering, New York January 1996 to Present
Industry Professor, Faculty Engineer in Residence
- Teaching assignments Wireless Systems Laboratory, Microwave Integrated Circuits and Analog Integrated Circuits
- Research faculty member of NYU WIRELESS
- Appointed as Faculty Engineer in Residence to provide technical and business assistance to NYU-POLY incubator companies, promote the values of invention, innovation, and entrepreneurship (i2e), mentor students in entrepreneur competitions, advise the Entrepreneurship and Innovation Association (EIA).
- Awarded the NYU-Poly Distinguished Teacher Award for 2011
- Collaboration with WICAT on cooperative communications testbed
- Collaboration with NYU Dental School to develop wireless dental application for Bruxism research
- Collaboration with NYU Medical School to develop wireless technologies for the operating room
- Collaboration with ECE department on radio development for brain implant sensor
- Faculty advisor for student club, Patent Pending, with the purpose of developing innovative products with the potential for commercialization
- Published 6 conference papers on cooperative communications and full duplex radio.
- Developed SDR Testbed using $600K NSF grant and also installed Poly's first antenna chamber. Received equipment donation ($85K) from Interdigital Corporation.
- Manage the ECE department laboratory facilities and technical staff

Asension Laboratories, Inc., New York July 2006 to Present
Founder and CEO
- Design and development of advanced antenna and communications products for the wireless and military industries.
- Industry partner with NYU-Poly working towards improving wireless capacity as part of the $800K NSF AIR grant.

Mode 1 Corporation, New York August 2001 to Present
Founder and President
- Engineering, research and design consulting company in the field of RF and microwave components and systems.
- Designed, tested and delivered numerous RF and microwave components and subsystems including high power and broadband amplifiers, antennas, power dividers, directional couplers, filters, attenuators and transceiver products.
- Customers include Motorola Solutions, Agilent Technologies, Aeroflex Corporation, ATC, MediaMark, Anadigics, Zetek, Astraion, BC Systems.

Motorola Solutions (formerly Symbol Technologies), New York Sept. 2003 to Feb. 2005
R&D Manager, Principal Engineer
- Engineering manager for the eleven-member research and development team. Responsible for the $1.3M budget of the RFID team. Also managed several outside consultants and university research programs.
- Member of the technical due diligence for the acquisition of the venture-backed RFID startup, Matrics.

Atrium Networks/Trimac Networks, New Jersey March 2001 to Jan. 2002
Co-Founder, Vice President of Engineering
- Part of a three member team that created the business plan and financial statements to close first round financing of $15M from three venture capital groups; Tallwood Venture, Lucent Venture Partners and Soros Private Equity.
- Managed the RF design team for the prototype development of OC-768 and OC-192 RF subsystems.

Agilent Technologies (formerly Hewlett Packard Test and Measurement)**,** NY/NJ/PA May 1996 to March 2001
Senior Technical Consultant, Systems Engineer
- Provided technical and business leadership and support in the delivery of strategic, complex and advanced test and measurement systems with applications up to 110 GHz.

Richardson Electronics, Valley Stream, NY April 1995 to May 1996
Microwave Applications/Sales Engineer
- Provided sales and engineering support at a global RF/Microwave component distributor. Key customers included wireless and military accounts in the Metro NY area. Reached 150% of sales quota.

Lockheed Martin Corporation, (formerly Sperry Corp), Great Neck, NY July 1983 to April 1995

RF/Microwave Research and Design Engineer

- Designed, fabricated and tested active and passive components for radar transmitter and receiver applications. These components used microstrip and stripline technologies covering frequency ranges from 400 MHz through 26.5 GHz.
- Principal Investigator and Cost Account Manager for several engineering projects including Solid State Transmit/Receive (T/R) modules and transfer switching networks.

ACADEMIC RECORD

Polytechnic University	PhD EE	June 2008
Polytechnic University	MSEE	January 1988
Polytechnic Institute of New York	BSEE	June 1983

PUBLICATIONS

- Microwave Journal, “Understanding Analyzer Choices: Spectrum, Signal, Vector and Real-time,” May 2013.
- IEEE Signal Processing in Medicine and Biology Symposium, “Heart Rate Measurement Utilizing Non-Contact RF Detection From Within the Mouth,” Submitted for Publication December 2012.
- IEEE Wireless and Microwave Technology Conference (WAMICON), “Single Antenna Full Duplex Communications using a Common Carrier,” April 2012.
- Microwave and Optical Technology Letters, "Reconfigurable microstrip patch antenna for WLAN Software Defined Radio applications,” March, 2012.
- IEEE International Conference on Wireless Information Technology and Systems (ICWITS), "Reconfigurable dual band microstrip patch antenna for Software Defined Radio applications", September, 2010.
- IEEE International Conference on Acoustic, Speech and Signal Processing (ICASSP), “Implementation of Cooperative Communications Using Software Defined Radios”, March, 2010.
- Agilent Application Note 5989-8973EN "MIMO Channel Modeling and Emulation Test Challenges", January 2010.
- IEEE Wireless and Optical Communications Conference (WOCC), "Cooperative Coding Implementation at the Physical Layer", May 2009.
- IEEE Communications Magazine, "Cooperative network implementation using open-source platforms", February 2009.
- Agilent Application Note 5990-3861EN “Techniques and Trends in Signal Monitoring, Frequency Management and Geolocation of Wireless Emitters” April, 2009.
- Microwave Product Digest, “Radar Measurement Comparison: Swept and FFT-Based Signal Analyzers, January 2009.
- Microwave Journal, Agilent White Paper “ADS Connected Solutions”, January 2008.
- Microwaves and RF Magazine, “Make Ultrawideband Transmitter Measurements”, May 2005.
- Microwave Products Digest, Published “Test Fixtures and SMT RF Device Characterization“, 2000.
- Wireless by Design Conference, San Jose, co-author with EEsof Division, Published, “Simulation Tools Aid in the Development of Wireless Communication Systems”, 2000.
- IEEE ARFTG Conference, Presented and Published, “A Novel Technique for Characterizing the Absolute Group Delay and Delay Linearity of Frequency Translation Devices”, 1999.
- European Microwave Conference, Published, “Highly Accurate Absolute Group Delay Measurement Technique for Frequency Translation Devices”, 1998.
- IEEE MTT Conference, Published, "A 400 Watt X-Band GaAs MMIC CW Amplifier", 1995.
- IEEE MTT Conference, Published and presented, "Solid State 6x6 Transfer Switch for Cylindrical Array Radar”, 1993.
- GOMAC Conference, Published and presented, "MMIC Insertion into C-Band T/R Modules for Systems Applications”, 1992.

PATENTS

- “Antenna Feed Network for Full Duplex Communication”, US Patent 8111640, February 2012.
- “High Isolation Signal Routing Assembly for Full Duplex Communication”, US Patent 8077639, December 2011.
- “Object Location Based Security Using RFID”, US Patent Number 7574732, August 2009.
- “Angle of Position Object Location System and Method”, US Patent Number 7170412, January, 2007.
- “Torque Wrench”, US Patent Number 7011001, March, 2006.
- “Method for Characterizing Frequency Translation Devices”, US Patent Number 6690722, February, 2004.
- "Method for Characterizing Delay of Frequency Translation Devices", US Patent Number 6459278, October, 2002.
- “Stimulus/Response System and Method for Vector Characterization of Frequency Translation Devices”, US Patent Number 6448786, March 2002.
- "Method for Characterizing Delay of Frequency Translation Devices", US Patent Number 6362631, March 2002.
- “Solid State Amplifier for Microwave Transmitter” US Patent Number 5561397, October, 1996.
- “Broadband MMIC Transfer Switch” US Patent Number 5510757, April, 1996.

Jeremy McCool

Education and Experience

- University of Central Oklahoma – Corporate Communication – Bachelor of Arts – 2005
- Columbia University, School of International and Public Affairs – Urban Policy, Renewable and Sustainable Energy – Master of Public Administration – 2011

- <u>Founder & CEO – HEVO Inc. – 2011-Present</u>

Mr. McCool conceived and created HEVO, which was founded on November 1st, 2011, in order to meet the opportunistic recharging needs Grid-Connected Electric Drive Vehicles (GCEDVs) in the commercial, municipal, military, and passenger markets. He is responsible for HEVO's daily operations, business direction, client relations, product development and the direction of its partners and team members. He also oversees the management, design, and development of wireless electric vehicle supply equipment (EVSE) using electromagnetic techniques and all corresponding software applications.

- <u>Associate – One Block Off the Grid – 2010</u>

Mr. McCool managed and supervised a "prequalification" solar energy project, which was undertaken by four summer associates and efficiently shortened the qualification period for potential clients. He also created an advanced search engine optimization (SEO) database containing the most popular web-searched solar energy keywords and highest page-ranked solar websites; expanding the firm's "followed" links with other solar companies, which aimed to increase their Google page rank. He also developed a community outreach catalog of events emphasizing "green energy" and environmentally conscious living in California, engaging over 100,000 potential clients.

- <u>Brigade Deputy Adjutant, 2nd Brigade Combat Team, 3rd Infantry Division – United States Army – 2008-2009</u>

Mr. McCool managed a staff of 35 soldiers performing all personnel and human resource activities for a 3,700 soldier unit including the processing evaluations, promotions, earnings statements, awards, duty rosters and combat readiness reporting. He managed all brigade command schedules and prepared brigade staff briefings. He also provided the first line of direct support to brigade and division ranking officers.

- <u>Lieutenant Platoon Leader, 1st Battalion, 64th Armor Regiment, 3rd Infantry Division – United States Army – 2006-2008</u>

Mr. McCool earned the Bronze Star, Purple Heart and Combat Infantryman Badge while leading and supervising over 1,000 combat missions in Baghdad, Iraq, during Operation Iraqi Freedom V (OIF V) in support of "The Surge." He performed over 100 humanitarian aid missions including a $30 million revamp of the Baghdad Children's Hospital and a $5 million renovation of the Iraqi Al-Kharkh Sports Club. He was also responsible for the training, development, welfare and supervision of a 35+ man Infantry Platoon consisting of a total of 17 Army combat vehicles and capital assets in excess of $15 million.

Activities

From 2011 to 2012, Mr. McCool was the President of the Columbia University School of International and Public Affairs' Energy Association, where he led the school's largest student organization where he amassed, funded and maintained an annual budget of $150 thousand. From 2010 to 2011, Mr. McCool served as the Director of the Columbia University Energy Symposium, the largest annual student-run event at Columbia University where he attracted key leaders in the global public and private energy sectors. Mr. McCool also co-founded the Columbia Energy Alumni Network (CEAN), which helps Columbia alumni network, share insights, engage in discussions about current, professional topics and enhance their knowledge and understanding of current policy and market trends, all within the energy field.

Steven Monks

Education and Experience

- University of Arizona – Bachelor of Arts Economics and East Asian Studies – Graduated 2010
- Columbia University, School of International and Public Affairs – International Energy Management & Policy – Master of Public Administration – 2012

- Founder & Chief Operating Officer – HEVO Inc. – 2012-Present

Mr. Monks manages the day-to-day operations of HEVO, a wireless Electric Vehicle Supply Equipment (EVSE) company, and coordinate's the company's partners and team members. He establishes and manages the company's human resources, negotiates agreements with manufacturers, supports corporate development strategy, market research, sales and marketing strategy, client and vendor relations and develops and presents investment memorandums.

- Senior Associate – Infinitas Energy Solutions – 2011-2012

Mr. Monks assisted the CEO of an energy services company by providing efficiency consultancy services from company inception through phase-two scale up, offering preferred services to commercial property managers. He negotiated agreements, assisted with project valuation models, supported market research, product control, sales and marketing strategy and client and vendor relations, developed and presented investment memorandums, designed, compiled and edited marketing materials for energy efficiency products and services and produced historical case studies and data models.

- Transportation Services Operator – Tucson Unified School District – 2004-2006

Mr. Monks supervised logistics and transportation routes for a school district of 60,000 students, transported students on standard and special needs routes with a maximum of 85 students and was appointed by transportation authority to represent a body of over 200 drivers at district board meetings.

- Owner & General Manager – Pennington Street Market and Boardwalk Cafe – 2003-2004

Mr. Monks owned and operated a restaurant and 24-hour retail marketplace. He managed accounting, sales, purchasing, marketing, employee productivity and negotiations, exceeded quarterly revenue targets by 70%, transferred ownership to new management, and supervised, hired and trained 15 employees.

Activities

Mr. Monks was the Project Manager for his 2012 Capstone Consultancy Project for Energias de Portugal at Columbia University's School of International and Public Affairs. He managed a team of eight students in the research, preparation and presentation of a 75-page report establishing a framework to evaluate the environmental, political and economic drivers of fuel price volatility for both conventional and renewable generation in Brazil, the United States, Iberia, Italy, Romania and Poland. Mr. Monks was also a member of the winning Columbia University team for the DOE Better Buildings Case Competition, where he provided a case analysis on market and policy measures to encourage the adoption of energy efficiency measures in the commercial building sector. Mr. Monks served as Director of Communications for the Columbia University School of International and Public Affairs' Student Energy Association, a student-run organization dedicated to building relationships among the school's students and energy sector practitioners in the field. In 2011, Mr. Monks was the Director of Operations of the Columbia University Energy Symposium, the largest annual student-run event at Columbia University that attracts key leaders in the global public and private energy sectors.

Budget

	EV Charger	Year 1	Year 2	Total
A.	Senior Personnel:PI/PD, Co-PI's			
	Dariusz Czarkowski	$11,000	$5,775	$16,775
	Francisco de Leon	$11,000	$5,775	$16,775
	Michael Knox	$9,600	$5,040	$14,640
	Total Senior Pers.	$31,600	$16,590	$48,190
B.	Grad Students			
	Student (Ph.D.)	$31,200	$31,200	$62,400
	Student (M.Sc.)	$24,000	$24,000	$48,000
	Total Students	$55,200	$55,200	$110,400
	Total Salaries	$86,800	$71,790	$158,590
C.	Fringe Senior Pers - 29%	$9,164	$4,811	$13,975
	Fringe Students - 5.74%	$3,168	$3,168	$6,337
	Total Fringe	$12,332	$7,980	$20,312
	Total Salaries,Wages and Fringe	$99,132	$79,770	$178,902
	Other Direct Costs:			
	Material and Supplies	$15,000	$15,000	$30,000
	Equipment	$24,000	$17,000	$41,000
	Publication Costs			
	Subcontract			
	Travel - Domestic			
	Other (Tuition)			
	Total Other Direct Costs	$39,000	$32,000	$71,000
				$0
	Total Indirect Costs 0%	$0	$0	$0
	Total Amount	$138,132	$111,770	$249,902
	TOTAL	**$138,132**	**$111,770**	**$249,902**

Budget Justification

The budget has been prepared following all current policies in NYU-Poly including salaries, stipends for Ph.D. students and M.Sc. students. Poly policies regarding fringe benefits have also been considered. Since this is an internal NYU project no indirect costs have been considered.

(i) Salaries

The project will be developed under the guidance of the proponent faculty members by a team composed of one Ph.D. student, one M.Sc. student, several GAs (graduate assistants), and undergraduate DP (design project) students. We have allocated one summer month salary to the PIs for the first year and a half summer month for the second year. The salaries have been adjusted by 5% up for the second year.

We need stipends for one Ph.D. student and one M.Sc. student for the two years. According to Poly rates the students will be paid at the following rates:

Ph.D. Student (after Qualifying)	$2,600.00 per month
M.Sc. or Ph.D. Student (before Qualifying)	$2,000.00 per month

(ii) Fringe Benefits

The fringe benefits are considered part of the direct cost at a rate of 29% for senior personnel (faculty) and 5.7% for the students.

(iii) Materials and Supplies

We request $15,000 per year (for a total of $30,000) for materials and supplies since we will be buildings several prototypes. We need heavy Litz wire for the coils, semiconductor switches, PCB boards, controllers, etc.

(iv) Equipment

For the first year we need a high quality power analyzer to evaluate the performance of the wireless charger. For example, we have considered the Yokogawa WT1800 High Performance Power Analyzer ($18,000) or the WT3000 Precision Power Analyzer ($20,000). Together with the power analyzer we need high precision CTs (current transformers), PTs (potential transformers), and appropriate probes capable of handling the high voltage and high current at high frequency required by the converters; we have allocated $4,000 to $6,000 for these interfaces.

For the second year we need an oscilloscope, for example the DLM 6000 or DL850V Scopecorder form Yokogawa and the associated high precision CTs and PTs. For this we have allocated $17,000.