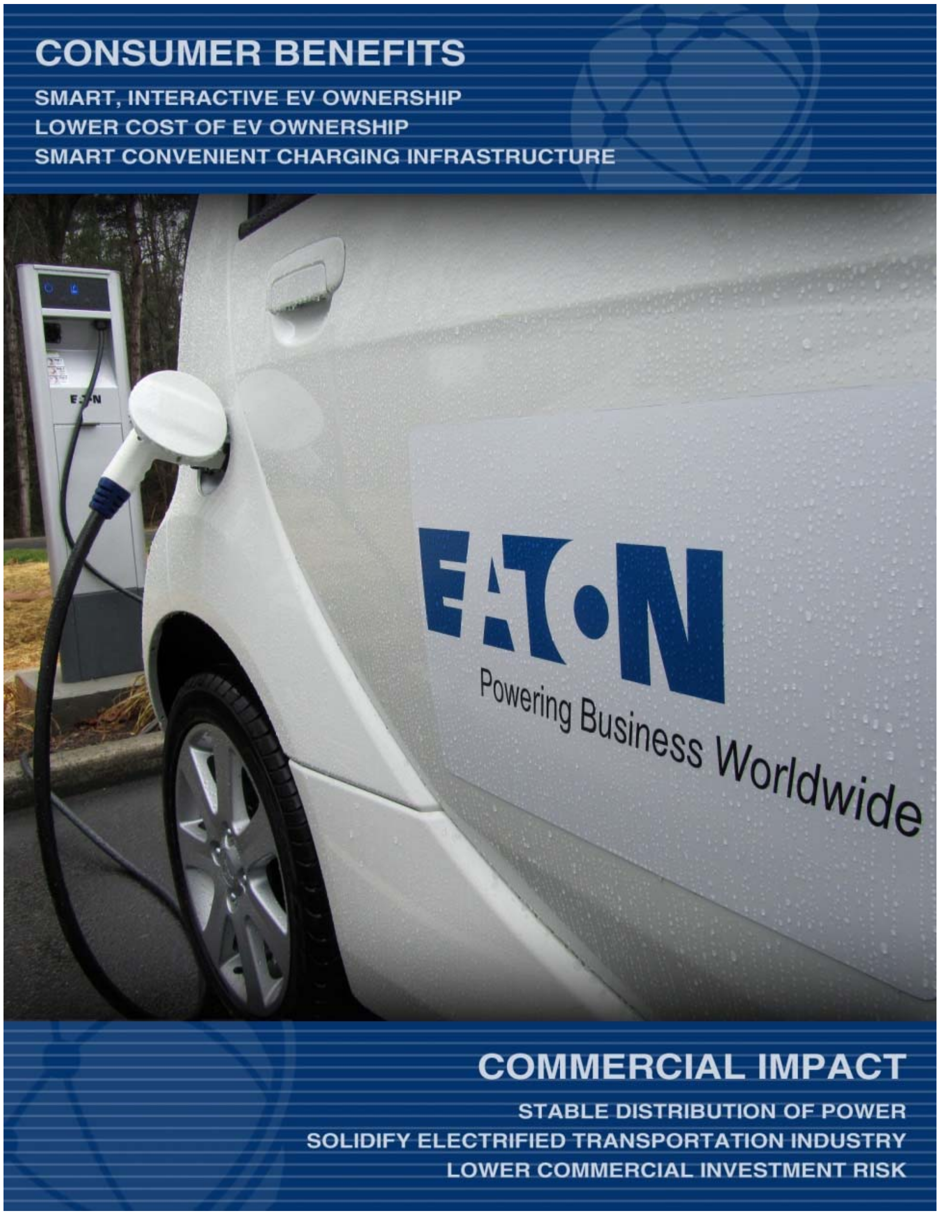
Smart Grid Enabled L2 EVSE for the Commercial Market

Final Technical Report



Prepared for:
U.S. Department of Energy

As part of:
DOE Award Number
DE-OE0000592

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June 05, 2015

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Smart Grid Enable L2 EVSE for the Commercial Market
Program Specifics and Participants

Date of Report: June 10, 2015

Federal Agency:	DOE/NETL
Award Number:	DE-OE0000592
Project Title:	Smart Grid Enabled L2 EVSE for the Commercial Market
Project Period:	May 1, 2012 through March 31, 2015
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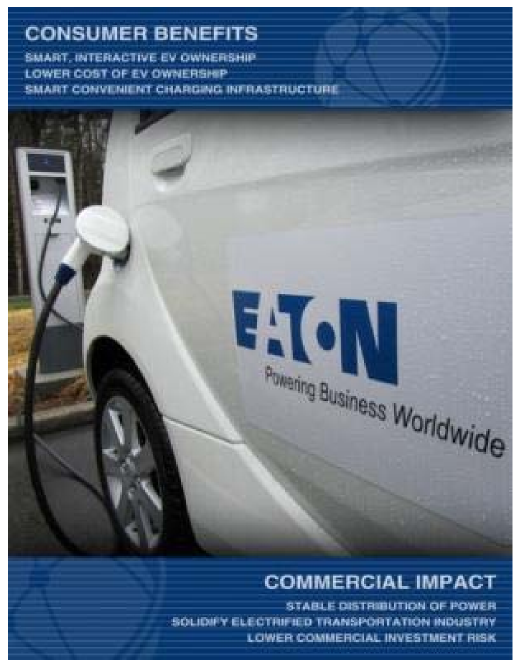

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2 Executive Summary

In 2011, the DOE issued Funding Opportunity DE-FOA-0000554 as a means of addressing two major task areas identified by the Grid Integration Tech Team (GITT) that would help transition Electric vehicles from a market driven by early adopters and environmental supporters to a market with mainstream volumes. Per DE-FOA-0000554, these tasks were:

- To reduce the cost of Electric Vehicle Supply Equipment (EVSE), thereby increasing the likelihood of the build out of EV charging infrastructure. The goal of increasing the number of EVSE available was to ease concerns over range anxiety, and promote the adoption of electric vehicles.
- To allow EV loads to be managed via the smart grid, thereby maintaining power quality, reliability and affordability, while protecting installed distribution equipment.

In December of that year, the DOE awarded one of the two contracts targeted toward commercial EVSE to Eaton, and in early 2012, we began in earnest the process of developing a ***Smart Grid Enable L2 EVSE for the Commercial Market*** (hereafter known as the ***DOE Charger***). The design of the Smart Grid Enabled L2 EVSE was based primarily on the FOA requirements along with input from the Electric Transportation Infrastructure product line (hereafter ETI) marketing team who aided in development of the customer requirements.

The EVSE market has evolved significantly from the start of this development, and some of the customer wants and needs were found to be quite dynamic. This caused a small amount of thrashing over the priority of some program objectives, however, by keeping a very open dialog with our DOE Program Manager, we were able to work through any issues around project scope and quickly refocus on technology development that would benefit both Eaton, and the goal of EV adoption via reduced cost L2 chargers.

The market dynamics faced during this program are highlighted in the commercial report (previously submitted), and one of the biggest changes that has occurred has been the very slow growth of the market compared to those predicted by major research and analysis firms. Eaton started with very conservative volumes compared to those predicted by Pike Research (now part of Navigant) and other analyst reports. We felt that or initial volume prediction of ~30,000 units per year was a very achievable number given the ramp of our existing L2 products and the prognostications of market analysts. But across the life of this development our sales projections fell as the market softened, and today stand at approximately 1/20th of that original value. This fact is a significant business challenge for Eaton, and is reflected in leaderships approach to launching DOE Charger technology into the market. At this stage, the real market volumes for EVSE do not justify a full release of the product developed. However, due to the extremely modular approach of the system architecture of the DOE charger, Eaton has a cleanly partitioned technology suite that stands ready to be deployed depending on market and customer requirements.

Figure 1 below shows the high level block diagram of the DOE Charger. The system architecture divides the processing needed for the system into two separate computational units, the Communications Board, shown in the center of the diagram, and the Supply Equipment Control Board (a.k.a. SEC board) with a left and right board shown depicting a Dual-By-Design system. This division of resources allows for flexible and cost efficient systems configurations, such as communicating and non-communicating versions, and dual and single variations of the EVSE.

Figure 1 - System Level Block Diagram

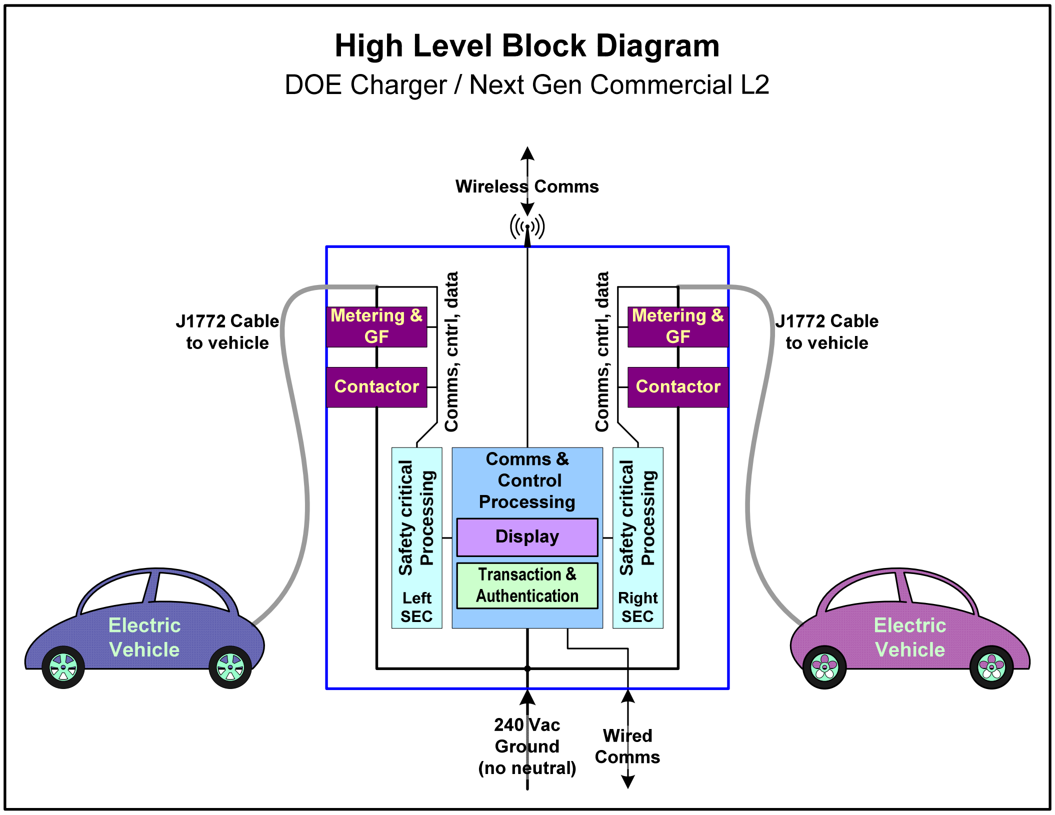
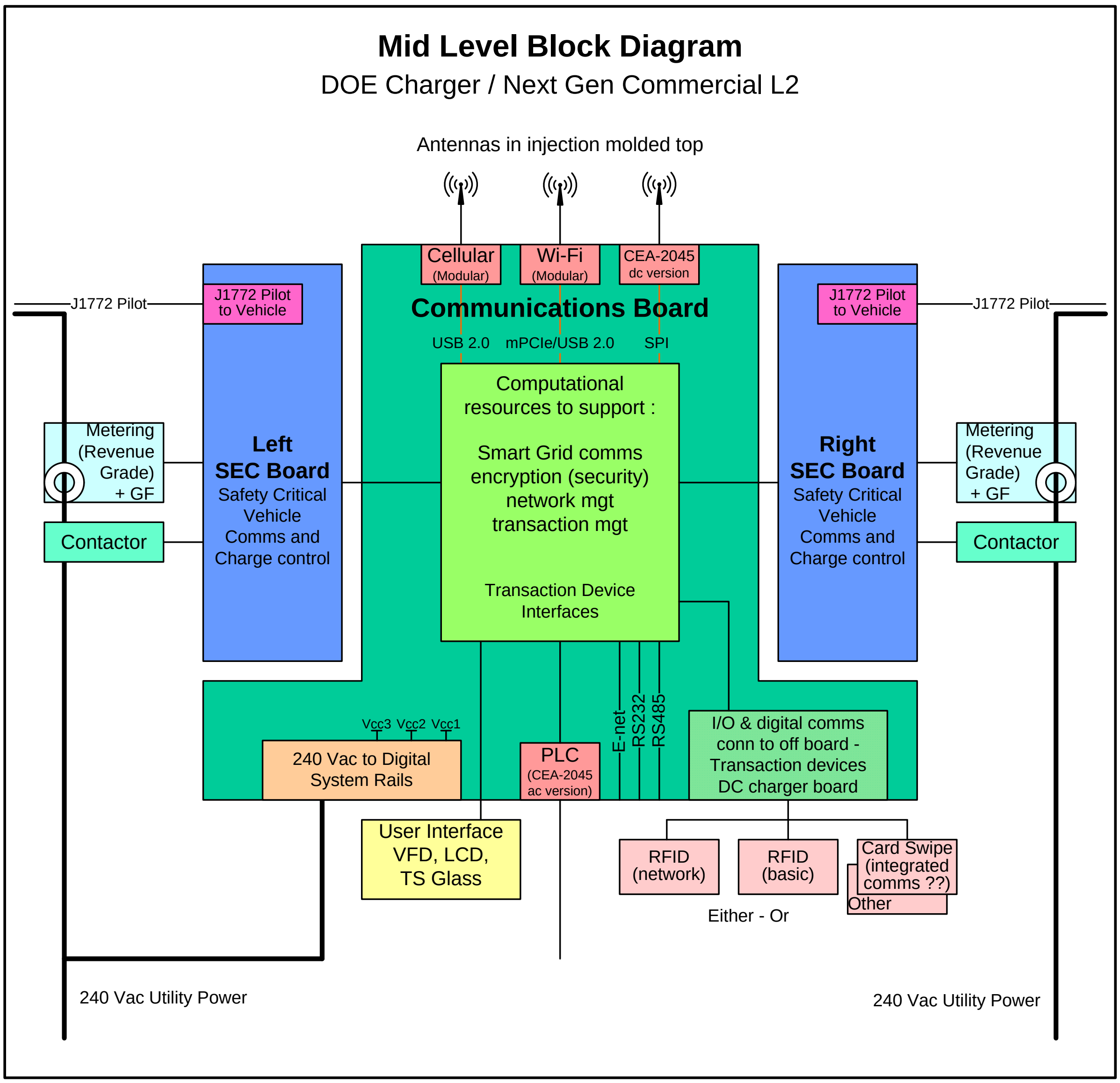


Figure 2 below show a more detailed block diagram of a dual charger system and specifics of the two main system boards are outlined in the following paragraphs.

The Communications Board is a highly flexible comms engine powered by an 800Mhz ARM A8 processor, running Linux as its OS. With the exception of the 100 Mb Ethernet connections, all of the communications required by the FOA are provided by modular plug-ins, which provides a number of benefits. It allows a customer to configure the communications of the unit to fit his needs without bearing the cost of unneeded interfaces, thus reducing EVSE cost while allowing for future changes as needed. The various physical form factors of the modular communication connectors allow for a spectrum of commercial (i.e. lower cost) devices to be selected to optimize cost of the EVSE, and by not hardwiring the communications on the board, the design allows for new communications protocols that are developed to be utilized as long as suitable Linux drivers are available. The availability of communications drivers for the Linux OS was one of the primary reasons for its choice to run the communications board. The comms board also houses the power supply for the system, and a flexible array of interfaces for transaction devices. This board is capable of driving a low cost display as well as higher capability graphic displays.

The SEC board provides the safety critical charging control for the EVSE, and is powered by a 120Mhz ARM M4 processor, running a real time OS. Multiple system monitors can safely de-energize the J1772 connector if any processor issues arise. Interrupts are used to run vehicle charging, and monitor control signals and ground fault sensors, thus keeping safety critical operations in a deterministic and well controlled FW space. The SEC has intrinsic 2% accurate energy metering so no external meter is needed for non-revenue grade metering, and in standalone mode, where no communications are required, the board is capable of driving the low cost character display. It can also interface to simple RFID devices and all-in-one credit card readers.

Figure 2 - Mid-level Block Diagram



Our major program partners, Duke Energy and Toyota Motors, have provided outstanding support toward this development effort, all at no cost to Eaton or the DOE. For this we owe both a tremendous debt of gratitude.

- Duke Energy, our utility partner, has provided strong insight into utility wants, needs, and objectives around EV's and EVSE, and their insights translated into several specification changes to address utility needs. Duke was the key proponent of the use of CEA-2045, which our team adopted after hearing very cogent arguments regarding the flexibility it provided to EVSE owners. Duke also provided us a vehicle from Tesla for high amperage testing (70A) with our DOE prototype, which allowed us to test at maximum current with a real world vehicle.
- Toyota, our automotive partner, has also been very a very valuable asset to our development effort by providing extremely salient market information on EV sales, and providing us with rolling stock of their EV's to with which to run additional high amperage testing (48A). However, one of the effects of the softening market for EVSE was a gradual reduced interest by Toyota, which was also predicated by their interest in other alternative fuel vehicles.
- We had one original partner, PNNL (Pacific Northwest National Lab), whose technology (Grid Friendly Appliance) we hoped to deploy in the DOE Charger, but regrettable we were unable to reach mutually agreeable terms for including it in our design.

Along with committing itself to a rock solid technological solution The DOE Charger team also committed itself to financial accountability and restraint in the use of DOE and Eaton funding. As reported in the quarterly SF-425 reports, program management for DE-OE0000592 and the development team kept a strong focus on expenses, and stayed well below budget limits in both phases of the contract.

As noted in the FOA, Electric vehicles – *"EVs—a term that includes plug-in hybrids, extended range electric vehicles, and all-electric vehicles-represent a key pathway for reducing petroleum dependence, enhancing environmental stewardship, and promoting transportation sustainability, while creating high quality jobs and economic growth."* [1] The DOE Charger team believes that as the EV/EVSE market grows past its current soft state, the technology developed under DE-OE0000592 will help enable this key pathway, and unlock the benefits of electric vehicles for the future. To foster these goals, Eaton has followed the tenets of the FOA, and worked to provide technology for a lower cost EVSE with advanced features, and smart grid capability. By working closely with the DOE to refine the goals of our program to match changing market needs and conditions, we believe we have met the full spirit of the funding opportunity, and have developed technology that can be deployed as market demand increases to help build EV Charging infrastructure, thereby increasing EV adoption.

In remainder of this document we highlight the project goals and accomplishments of the program, the design and testing activities across the multiple engineering disciplines used to produce

[1] Funding Opportunity Number: DE-FOA-0000554, 06/03/2011, pg. 4

our prototypes and field-demonstration units, and we discuss the lessons learned in each of those disciplines, and the future status of the design. And finally we provide a brief synopsis and discussion of the results of our program testing outputs, with full reports included in the appendices.

3 Project Goals and Accomplishments

Table 1 below provides an overview of the goals of the "DOE Charger" program and their alignment with the wants of the ETI group (Electric Transportation Infrastructure), along with status/notes on the state of the listed features. The table provides a comprehensive list of the program goals, but it's worth touching on some of the more important aspects of the development in greater detail.

- **Achieve 50% cost out** – The full DOE effort, i.e. the mechanical design with electronics, was quite successful and easily meets the cost out goal of the program. After weighing the cost of market introduction of the full DOE design against the significantly lower volumes from those predicted by market research and analysis groups, it has been determined that this approach is not currently economically viable. For this reason, ETI has chosen to take an market driven approach to rolling out of the technology developed under DE-OE0000592.

  ETI is currently following a strategy of using the Supply Equipment Controller (hereafter SEC) board to provide a significant cost out to its existing EVSE portfolio. In addition, the Residential EVSE group at Eaton is also planning a cost out using the SEC board. Further cost out opportunities will be pursued as favorable market conditions present themselves, with the communications board being eyed as a strong cost out opportunity in late 2015 / early 2016.
- **CyberSecurity** – Strengthening the DOE charger against potential hacking was a prime objective of DE-OE0000592. Given the requirement for the DOE Charger to be network connected for Smart Grid functions and transactions / control, the need for strong cybersecurity measures was paramount. Given the computational horsepower needed to provide intelligent EVSE (e.g. the Eaton DOE Charger uses an 800Mhz processor for its communications board), not only did the design team need to make sure that the EVSE provided data integrity and confidentiality on the network, but that the processor itself could not be compromised and used as a malicious internet Bot – *"An Internet **bot**, also known as web robot, WWW robot or simply **bot**, is a software application that runs automated tasks over the Internet. Typically, bots perform tasks that are both simple and structurally repetitive, at a much higher rate than would be possible for a human alone."* [2]
  To meet the goal of cybersecurity, the team looked at both physical and electronic security. As is noted in the detailed INL assessment section of this document, this exercise was mostly successful, with a few notable exceptions.
    - Mechanical – after diligently working with lock suppliers to find a hardened but reasonably priced lock for the physical enclosure, the team was very surprised

[2] Wikipedia http://en.wikipedia.org/wiki/Internet_bot#Malicious_purposes

to find that the lock could be compromised by a Bic ink pin cap, as noted in the INL cybersecurity report. Response from the vendor on this situation was not acceptable, and if the enclosure is industrialized in the future, a different, more secure, mechanism will be chosen.
    - Electronic / FW – We feel Eaton performed quite well in this category, especially given the intrinsically unsecure nature of many of the protocols being requested for use in EVSE by industry. However, INL did find a couple of places where improvement is warranted, and several bugs have been filed on our tracking system to ensure recommendations and observations by INL will be run to ground on future spins of HW and FW.
- **Metering solutions** – The DOE charger development has yielded an integrated metering solution and an as market need arises, a higher accuracy external solution for possible deployment.
    - The SEC board provides integrated metering with 2% accuracy on board. This level of accuracy was deemed more than sufficient by our Utility partner Duke Energy, and allows for a very low cost solution for energy metering.
    - For revenue grade accuracy requirements, a low cost external metering solution with 0.5% and 0.2% accuracy was designed to directly connect to the DOE electronics. The meter was designed to be 0.5% accurate without any need to calibrate it to the CT (current transformer) used to measure current. This allows the meter to be removed from a system and replaced without having to replace the CT. For 0.2% accuracy, the CT can be calibrated to the meter to provide extremely high accuracy.

      This effort was taken on at zero cost to the DOE by the MRBU (Meters and Relays Business Unit, one of our sister business groups). The meter board has been UL certified, and an interface to the meter has been included on the Communications Board for future use if needed. Full design collateral for the meter has been provided to ETI for its use if market demand call for a higher accuracy solution than the integrated metering supplied by the SEC board.
- **Communications Protocols** – Eaton took on the challenging task of providing all 5 requested communications protocols as part of DE-OE0000592, and here the results of our efforts are mixed, with three of the five protocols (Ethernet, Cellular Modem, and Wi-Fi) operationally tested, and HW support provided for the remaining two (ZigBee and Power Line Carrier, a.k.a. PLC).

  Ethernet, Cellular modem, and Wi-Fi have been tested in the lab, and cellular connectivity was used to gather charging information from our demonstration unit deployed in the field.

  The communications board was designed to support ZigBee and PLC communications via a CEA-2045 DC MCI (Modular Communications Interface) and a CEA-2045-AC MCI respectively. Working with our Utility partner Duke Energy, Eaton chose the CEA-2045 platform as a means to support station owner flexibility around communications. By incorporating both CEA-2045 MCI's, we have provided an interface that allows station owners to select and own the interface used to monitor and control the charger, thus giving them the ability to unify their communication's strategy with other Smart-Grid devices they may have in play. Regrettably, progress on CEA-2045 products has been slower than anticipated by industry, and the needed Linux driver functionality required to make module integration seamless lags even further behind. It is anticipated that over time this technology will gain wide acceptance in the Smart Grid space, and the ETI product line will continue to monitor development of this technology, so it can react rapidly if sufficient volumes for this functionality arise.

- **Communicating HMI** – In the commercial space, one of the challenges faced by Eaton's current EVSE offering is the ability to provide messages as needed to the end users of our chargers (i.e. people charging vehicles). The current commercial interface uses only icons and LED's to inform the end user of needed actions and operational status, and as part of DE-OE0000592, the DOE Charger design team set out to develop a low cost HMI that allowed significantly better message capability to EVSE end users. The end result of this effort was the selection and integration of a 4-line by 20-character transflective LCD display that provides sunlight readability and an integrated backlight for low light readability. This low cost display also contains an integrated heater to prevent sluggish updates during for cold weather operation. With this interface, the DOE charger provides the ability to display detailed status, directions and troubleshooting codes to the equipment owners and end users, and provides the owner the capability of adding targeted messages to their end users.
- **Secure In Field Upgrade** – This feature ties into CyberSecurity by only allowing Eaton signed FW to be loaded into the charger, but it also has significant commercial benefit in that both networked and non-networked chargers are accommodated by the feature. The SEC board of the DOE electronics is programmable via either USB Flash, or via Modbus messaging in a networked environment. The Communications board, while geared toward networking, and therefore network upgrades, can also accommodate FW upgrades via USB. The upgrade images are run through a hash function that provides a key which can be checked to verify the code has been generated by Eaton.

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Table 1 - Program Goals with Status/Notes

Scope Analysis						
DE-OE0000592						
FEATURE	In FOA 554 response	Marketing Req.	"Nice to have"	Option		Status / Notes
Achieve 50% cost reduction	x	x				Full DOE meets 50% cost out, current incremental deployment can meet 50% if business case develops
Input 208/240V, 50/60Hz, 40A	x	x				All voltages and frequencies supported, unit capable of dual operation at 72A (limited by upstream breaker sizing).
Design support for up to 80A in the future			x			Supports industry max cable current of up to 75 amps
Smart Grid						
Revenue Grade Metering	x	x		x		2% metering intrinsic to product. 0.5% / 0.2% MRBU project closed due to extremely low volume. Design collateral transferred to Divisions for future use.
Demand Response Controls	x			x		ModBus register mechanisms in place for control,
Two way communication features	x			x		DOE communications are two way.
Transaction Management Systems	x	x		x		HW support in place, CC and RFID In development by ETI for 2015 (non-DOE funded)
Communication Protocols on Motherboard						
Ethernet	x	x				Working
PLC	x	x				HW support via CEA-2045
RS232	x	x				Working
RS485	x	x				Working
Communications protocols (plug-in through USB2/other)						
Cellular	x	x		x		Working
Wi-Fi	x	x		x		HW tested, but no protocol support in FW
ZigBee	x			x		HW support via CEA-2045
Vehicle Communications						

	J1772	x	x			Working
	PLC	x				Solution developed for HPGP, removed from scope due to lack of business case
Design support for future Cloud Options						
	Grid Point		x		x	All replaced by OCPP, slated for introduction in 2016 based on market need
	ChargePoint		x		x	
	Drive Green (rebate)			x	x	
	SAP			x		
	"Istore" Upgrade			x		
Building Automation						
	BACnet	x	x		x	HW support in place, but FW not pursued due to lack of business case.
User Interface (HMI)						
	Module is replaceable		x			Cost too high
	Status reporting		x			Working
	Intuitive		x			
	User guidance		x			Supported, no market requirements
	Messages remotely upgradeable		x			Supported, no market requirements
	Service interface		x			No marketing requirements provided to date.
	Error reporting		x			Error codes displayed on HMI
	Economic		x			Cost significantly lower than existing design.
	Graphical		x			HW support in place
	Multi language support		x			Character display supports multi language, no market requirement at this time.
USB 2.0 for data collection and upgrade				x		Upgrade via USB complete,
Remote Troubleshooting			x			Error codes retrievable via network
Reduced installation cost		x	x			Fewer steps to complete DOE install, same for current enclosure.
Product Configurations						
	Wall Mount	x	x			DOE and current design
	Pedestal	x	x			DOE and current design
	Pole Mount Kit		x			No marketing requirements provided to date
	Parking Meter					No marketing requirements provided to date
	Kiosk Model			x		Under development for 2015
Vandalism secure / Security		x	x			CyberSecurity designed in
Enclosure						
	NEMA 3R	x	x			DOE chassis passed, current design scheduled for test

NEMA 4X			x			DOE chassis could be 4X, but current chassis cannot be made 4X capable.
Cord Management		x				Concepts generated, removed from scope by ETI leadership
Remote display		x		x		No marketing requirements provided to date
Design support for dual units		x				Dual by design
Low Quiescent Power	x					Power higher than specified, under investigation
Grid Friendly Appliance	x					Could not reach development terms with PNNL