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Cyberattacks and Defenses for EV Charging

Jay Johnson, Sandia National Laboratories

9th Embedded Security in Cars (escar) USA Conference

Ypsilanti, Michigan

June 15, 2022

SAND2022-XXXX

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U.S. DEPARTMENT OF ENERGY

NNSA

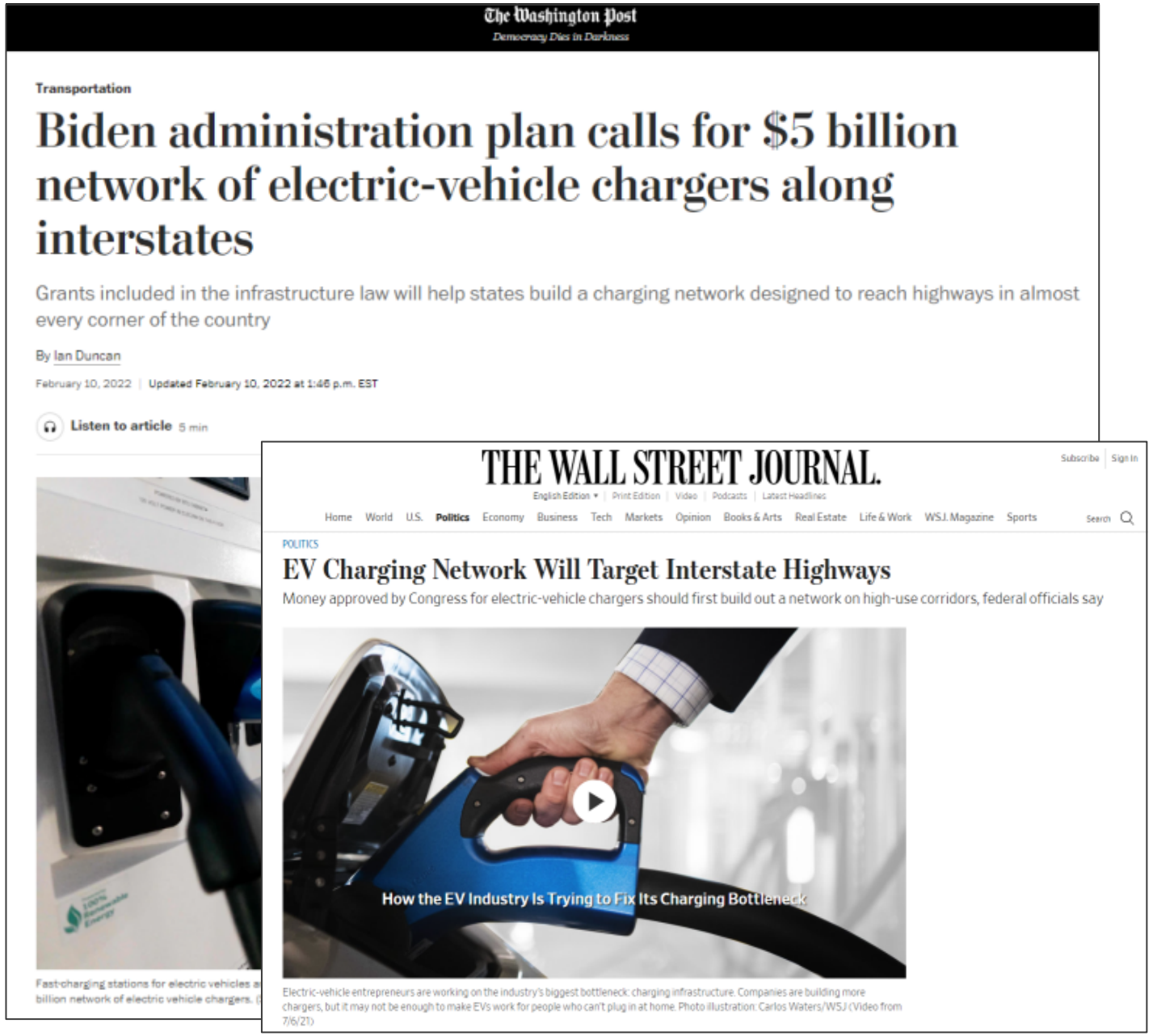
EV Charging Context

DOE public charger estimates:

- 2021: 46,500 chargers available today
- 2030: Demand for 600,000 chargers

$1T infrastructure law included $5B for EV charger installations

- Plan: **5-year roll-out of a network of EV chargers** along interstate highways, rural corridors, and underserved or disadvantaged communities
  - Target: 500,000 chargers with one every 50 miles of interstate highway
  - States have until Aug. 1, 2022 to submit plans for their funding
  - There will be federal interoperability and cybersecurity requirements for state installations
  - Question: **what security issues need to be addressed?**



The Washington Post
Democracy Dies in Darkness

Transportation

Biden administration plan calls for $5 billion network of electric-vehicle chargers along interstates

Grants included in the infrastructure law will help states build a charging network designed to reach highways in almost every corner of the country

By Ian Duncan

February 10, 2022 | Updated February 10, 2022 at 1:46 p.m. EST

Listen to article 5 min

Fast-charging stations for electric vehicles a
billion network of electric vehicle chargers. (

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POLITICS

EV Charging Network Will Target Interstate Highways

Money approved by Congress for electric-vehicle chargers should first build out a network on high-use corridors, federal officials say

How the EV Industry Is Trying to Fix Its Charging Bottleneck

Electric-vehicle entrepreneurs are working on the industry's biggest bottleneck: charging infrastructure. Companies are building more chargers, but it may not be enough to make EVs work for people who can't plug in at home. Photo illustration: Carlos Waters/WSJ (Video from 7/6/21)

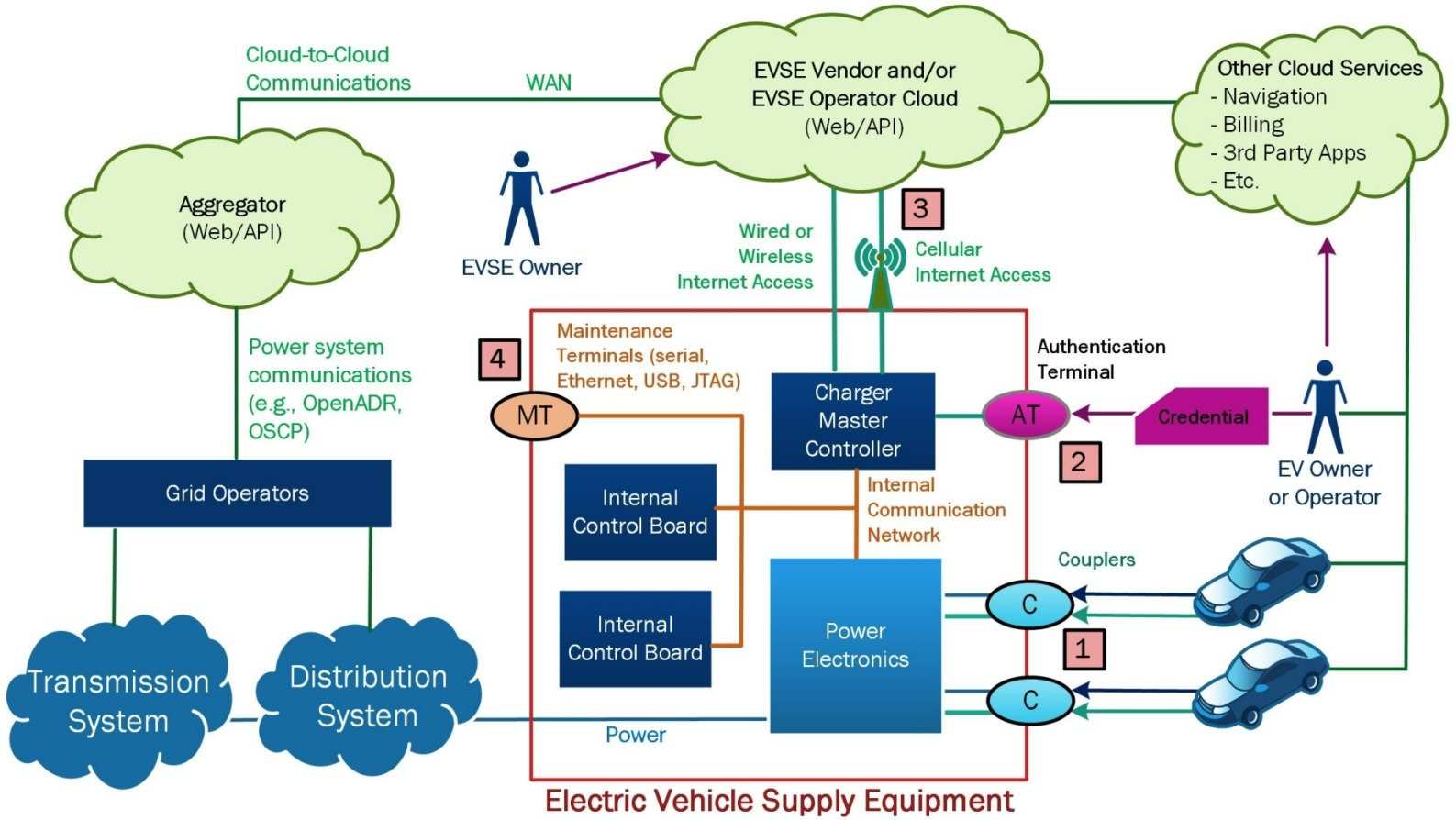
- https://www.wsj.com/articles/ev-charging-network-will-target-interstate-highways-11644487200
- https://www.washingtonpost.com/transportation/2022/02/10/electric-vehicle-charging/
- https://afdc.energy.gov/stations/states

Electric Vehicle Charger Pen Testing Research

- Goal: **Discover and patch EV Supply Equipment (EVSE) vulnerabilities before exploitation**
- Sandia/ANL investigation
  - 8 high power and 4 Level 2 chargers (from 10 companies)
  - 2 backend cloud networks
  - OCPP 1.6
  - ISO 15118-2 PKI requirements
- Results
  - Vulnerability information was provided to industry partners through secure channels
  - Partners addressed many of the findings, or incorporated changes/mitigations into product roadmaps
- Sandia **surveyed known/published EVSE vulnerabilities and exploits** to understand risks faced by EV charging community

EVSE Cybersecurity Vulnerabilities

- Four interfaces of primary interest
  1. **EV couplers** – CCS, CHAdeMO, etc.
  2. **User terminals** – touch screens, credit card swipes, etc.
  3. **Internet connections** – cellular or wired backhaul networks
  4. **Maintenance terminals** – local debugging and service interfaces (USB, ethernet, etc.)
- **Vulnerabilities exist for each interface**
  - The following slides include a subset of vulnerabilities that may be of interest for the industry



EV Connectors – Losing the Car Keys and Brokenwire

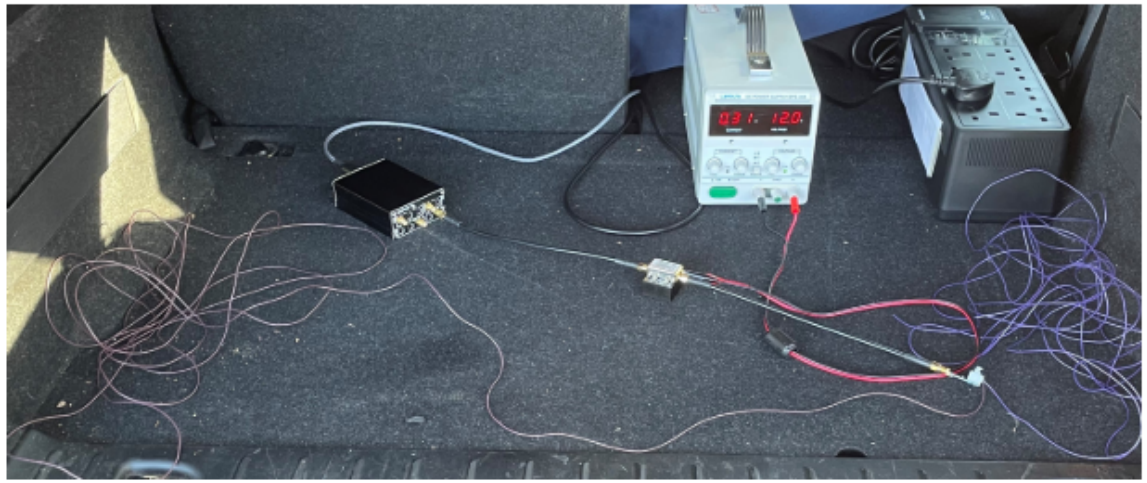
Brokenwire

Vulnerability in the Combined Charging System for Electric Vehicles

In 2019, University of Oxford showed you could sniff Personally-Identifiable Information (i.e., billing information) radiated from CCS charging cables

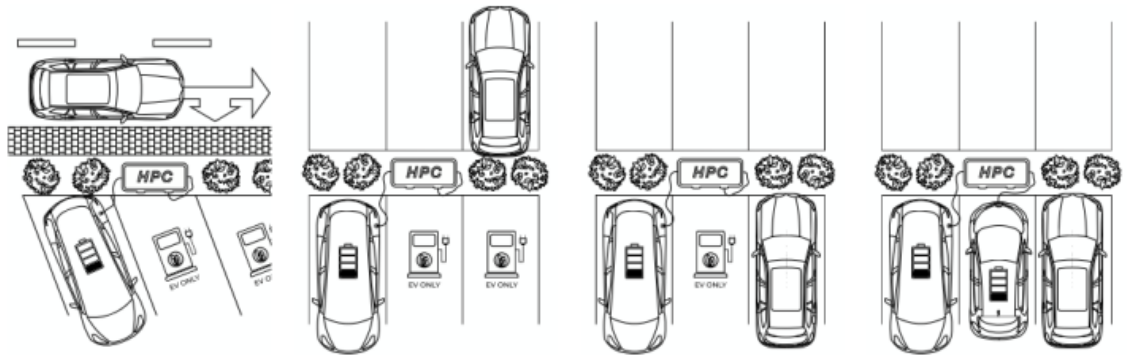
In 2022, the University of Oxford and Armasuisse S+T extended that work to remotely terminate CCS sessions.

- Radio frequency (RF) interrupts necessary CCS control communication between the vehicle and charger → Aborts charge sessions.
  - Inexpensive software defined radio (SDR)
  - Less than 1 W of power.
  - Successful at distance of 47 m.



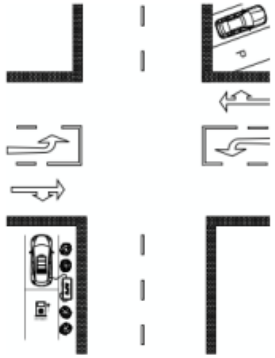
Equipment for attack, including antennas, SDR, and UPS

Attack Scenarios

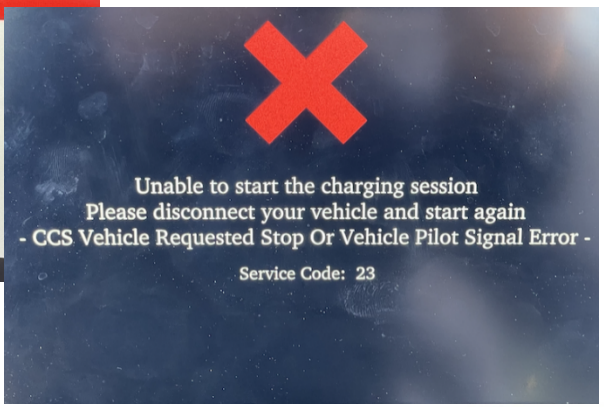


Drive-by attack

Proximity attacks: car-to-car



Remote attack



https://www.brokenwire.fail/
https://www.usenix.org/conference/usenixsecurity19/presentation/baker

EV Connectors – Java Log4j/Log4Shell Privilege Escalation

Trend Micro used CCS comms to exploit Apache logging package Log4j.

- Log4j vulnerabilities + *V2G Injector* + HomePlug GreenPHY key collection flaws = escalated access privileges on simulated EVSE running the RISE-V2G Java stack.
  - Encoded XML payload delivered to EVSE using the Vehicle-to-Grid Transfer Protocol (V2GTP) layer.
- Vehicles also vulnerable to this attack.

Exploits & Vulnerabilities

Examining Log4j Vulnerabilities in Connected Cars and Charging Stations

In this entry we look into how Log4j vulnerabilities affect devices or properties embedded in or used for connected cars, specifically chargers, in-vehicle infotainment systems, and digital remotes for opening cars.

By: Sébastien Dudek
December 23, 2021
Read time: 8 min (2288 words)

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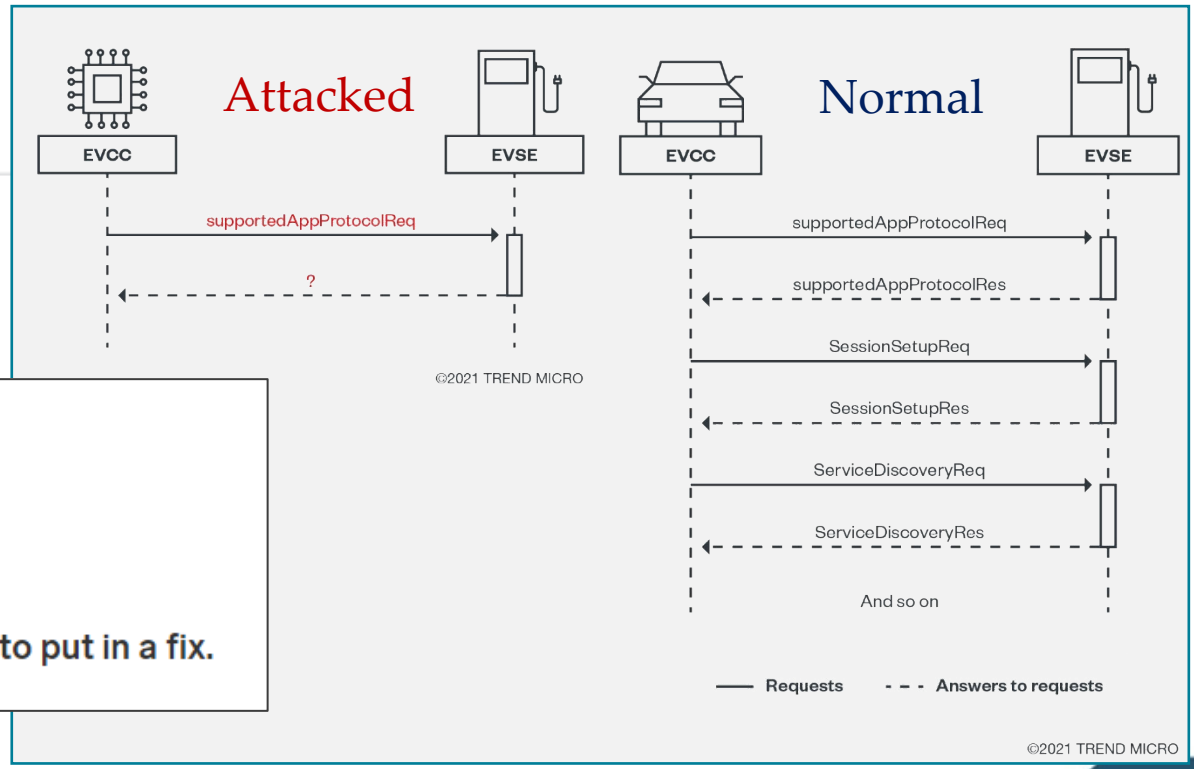


LILY HAY NEWMAN SECURITY DEC 10, 2021 2:54 PM

‘The Internet Is on Fire’

A vulnerability in the Log4j logging framework has security teams scrambling to put in a fix.

- https://www.trendmicro.com/en_us/research/21/l/examining-log4j-vulnerabilities-in-connected-cars.html
- https://www.wired.com/story/log4j-flaw-hacking-internet

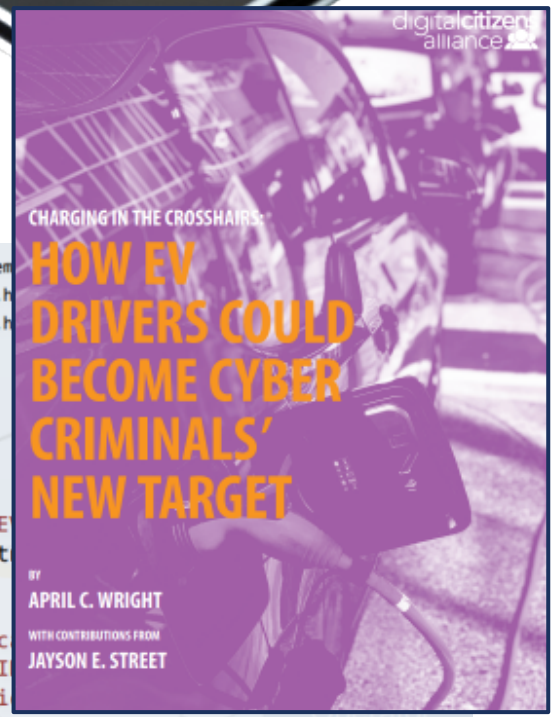
EVSE Operator Interfaces – Authentication Issues

Options for authenticating/billing driver for charging:

- Credit Card
  - Cyber criminals use skimmers/shimmers steal card information.
- RFID/MIFARE
  - Cloning risks of using RFID tags and MiFare Classic (13.56 MHz contactless smart cards)
  - Drivers can be tracked if RFID and Charging Station ID are broadcast (e.g., via unencrypted OCPP 1.6) to e-mobility roaming providers.
- NFC/phones
  - Some smart phone apps include EVSE management and vendor cloud interface vulnerabilities.
- Plug-and-Charge Functionality
  - Questions raised regarding the ISO 15118-2 PKI security implementation.
    - These are being addressed in ISO 15118-20/SAE PKI project.

Proxmark3 for sniffing, reading, and cloning RF Tags

MIFARE




```
<soapenv:Envelope xmlns:soapenv="http://schem
                  xmlns:v2     ="http://www.h
                  xmlns:v21    ="http://www.h

   <soapenv:Header/>
   <soapenv:Body>
      <v2:eRoamingAuthorizeStart>

         <v2:SessionID>?</v2:SessionID>
         <v2:EVSEID>DE*GEF*1234567*1</v2:E
         <v2:PartnerProductID>AC1</v2:Part

         <v2:Identification>
            <v21:RFIDmifarefamilyIdentific
               <v21:UID>CAFEBABE23</v21:UI
            </v21:RFIDmifarefamilyIdentifi
         </v2:Identification>

      </v2:eRoamingAuthorizeStart>
   </soapenv:Body>
</soapenv:Envelope>
```

OCPP disclosing EVSE ID and

- M. Dalheimer, "Ladeinfrastruktur für Elektroautos: Ausbau statt Sicherheit (Charging infrastructure for electric cars: expansion instead of security)" in Proceedings of the 34th Chaos Communication Congress; 2017.
- A. Friedland, "Security and Privacy in the Current E-Mobility Charging Infrastructure. In Proceedings of the DeepSec; 2016.
- A.C. Wright, J.E. Street, "Charging in the Crosshairs: How EV Drivers Could Become Cyber Criminals' New Target; 2019.
- INL, "Cyber Security Research and Development: Cyber Assessment Report of Level 2 AC Powered Electric Vehicle Supply Equipment," 2018.
- Practical Considerations for Implementation and Scaling ISO 15118 into a Secure EV Charging Ecosystem, 2019.

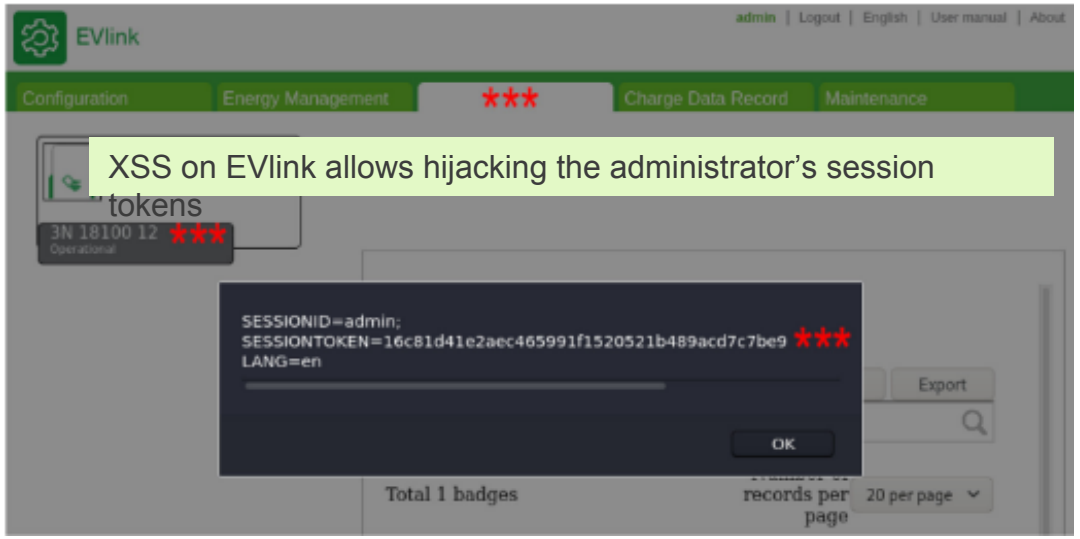
Internet Interfaces – Web

Nasr *et al.* reported multiple web vulnerabilities for the Schneider EVlink and other products including:

- Cross-Site Scripting (XSS)
- Cross-Site Request Forgery (CSRF)
- Server-Side Request Forgery (SSRF)
- javascript information exposure

INL found EVSE web vulnerabilities including:

- Missing authentication methods such as client-side validation
- Unencrypted HTTP for logon credentials
- Unsanitized logon fields vulnerable to SQL injection attacks



Vulnerabilities in EV Charging Management Systems

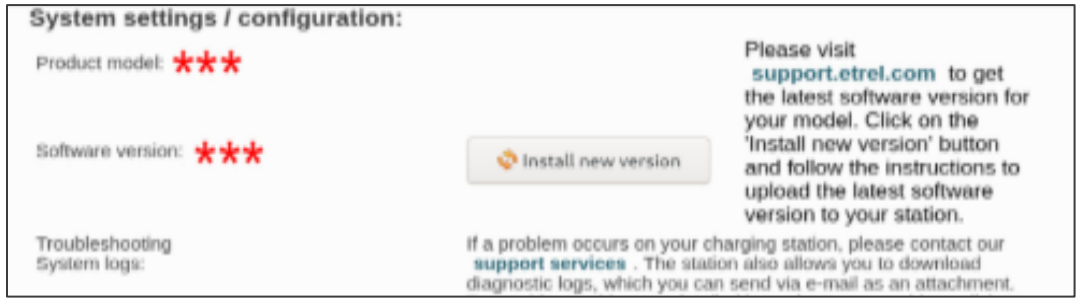
		CWE-ID/Vulnerability												
		79	89	200	306	321	352	425	798	799	918	942	942	1236
	EVCSMS	Cross-Site Scripting (XSS)	SQL Injection (SQLi)	Information Disclosure	Missing Authentication	Embedded Secrets	Cross-Site Request Forgery (CSRF)	Forced Browsing	Hard-Coded Credentials	Missing Rate Limit	Server-Side Request Forgery (SSRF)	CORS Misconfiguration	FCDP Misconfiguration	CSV Injection (CSVi)
Firmware	EVlink	✔		✔			✔	✔	✔	✔	✔			✔
	xChargeIn				✔					✔			✔	
	CSWI Etrel	✔			✔				✔		✔		✔	
	SmartFox								✔	✔				
	Keba				✔								✔	
Mobile	ChargePoint					✔								
	Go					✔				✔				
	EV Connect					✔				✔				
Web	OASIS Portal	✔					✔							
	BaSE EVMS		✔							✔				
	Ensto CSI				✔					✔				
	FCEIS									✔		✔		
	ICEMS		✔							✔				
	PiControl	✔					✔		✔	✔	✔	✔		
	Garo CSI				✔					✔				
	Lancelot									✔		✔		

T. Nasr, S. Torabi, E. Bou-Harb, C. Fachkha, C. Assi, "Power jacking your station: In-depth security analysis of electric vehicle charging station management systems," Computers & Security, Volume 112, 2022

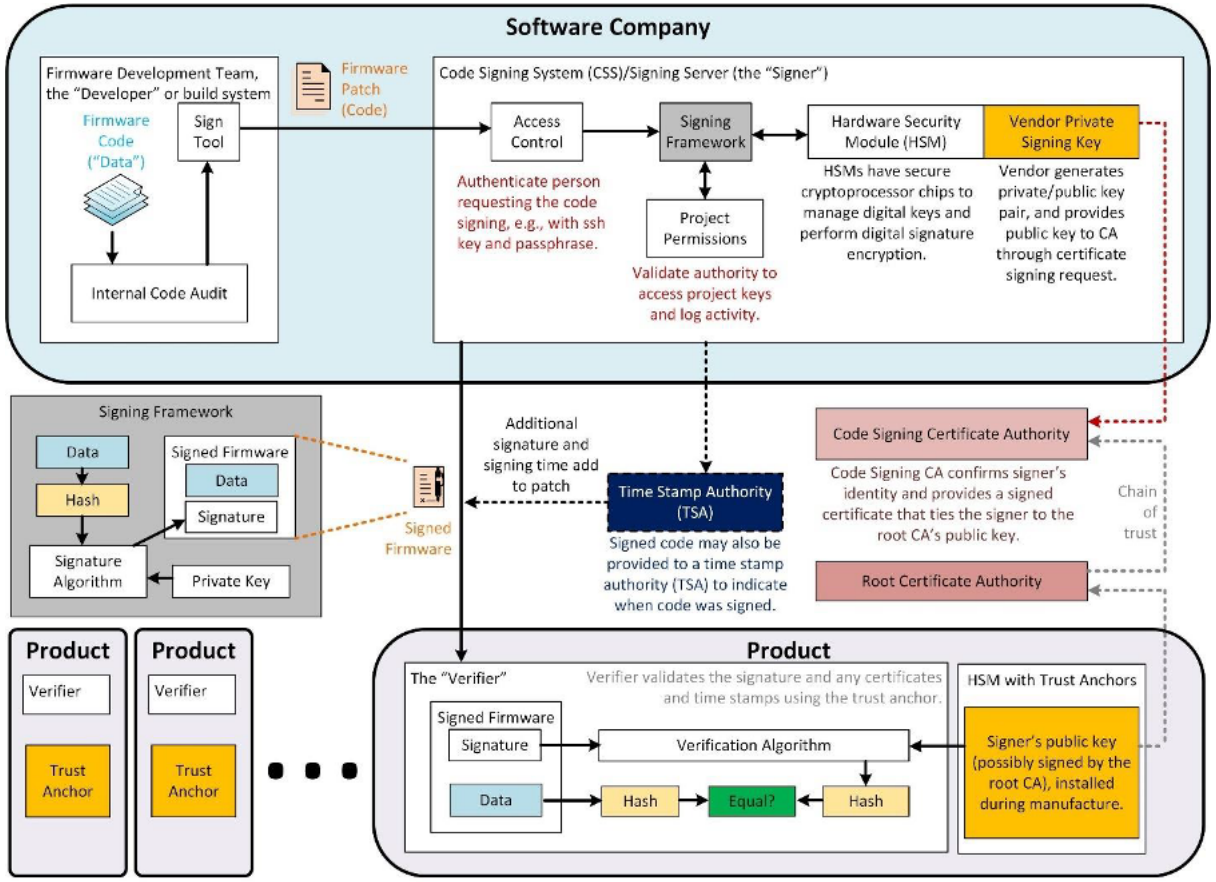
Maintenance/Internet Interfaces – Malicious Firmware Updates

Many examples of unsigned, unvalidated EV charging firmware

- INL Case 1: Firmware automatically updated when USB drive connected
- INL Case 2: Sniff traffic, steal FTP credentials, compromised server, push out modified firmware to all EVSE devices
- Pen Test Partners: platform without authorization did not require firmware signing
- Nasr *et al.*: Etrel firmware downgrade attacks



Etrel allows attacker with administrator privilege to downgrade the EVSE firmware



Example Secure Code Signing Architecture

- Cyber Assessment Report of Level 2 AC Powered Electric Vehicle Supply Equipment, INL Technical Report INL/MIS-18-45521, May 2018.
- https://www.pentestpartners.com/security-blog/smart-car-chargers-plug-n-play-for-hackers/
- T. Nasr, S. Torabi, E. Bou-Harb, C. Fachkha, C. Assi, Computers & Security, Volume 112, 2022.
- J. Johnson, I. Hanke, "Recommendations for Distributed Energy Resource Patching," Sandia Report SAND2021-11150, September 2021.

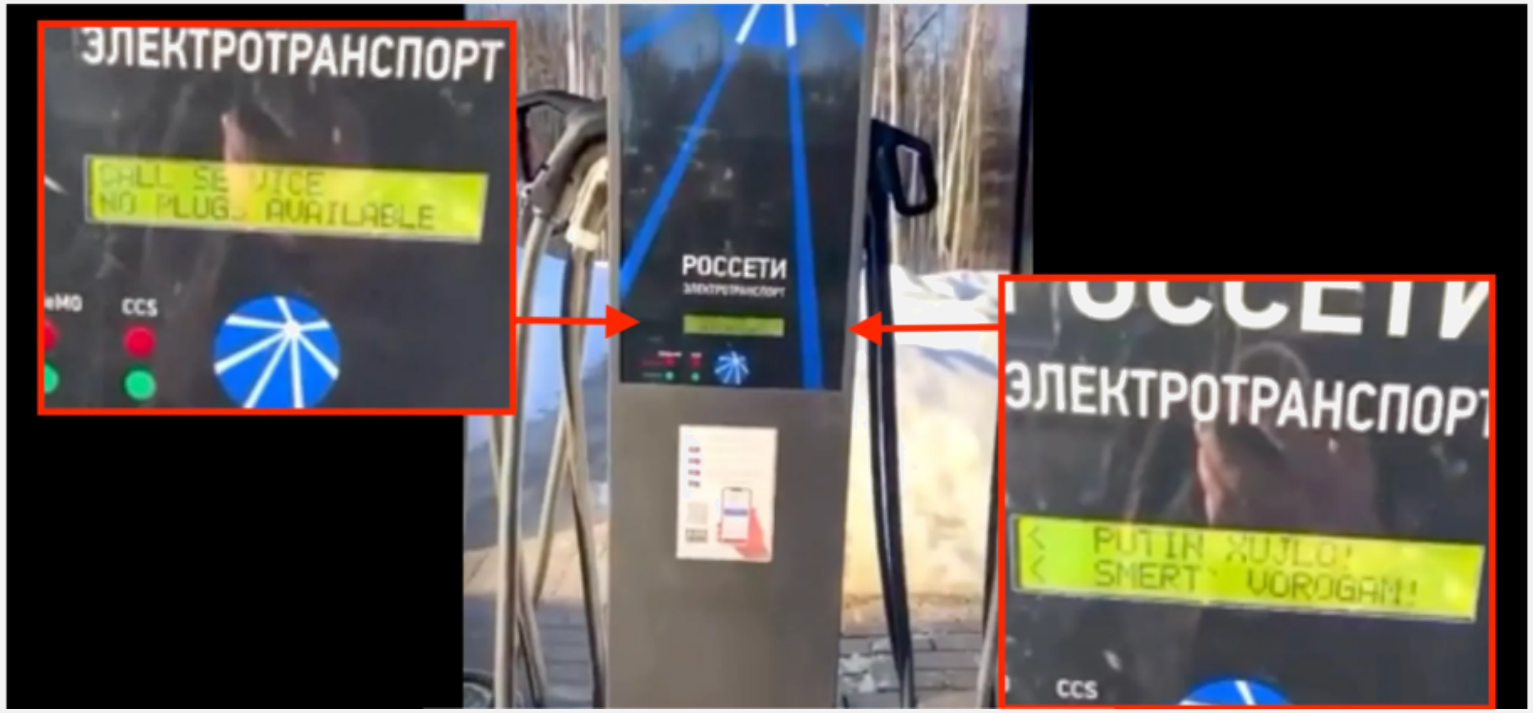
Malicious Firmware Updates and Supply Chain Vulnerabilities

Russian company, *Gzhelprom*, outsourced components in EV chargers to a Ukrainian Company, *Autoenterprise*

- Charging stations installed in 2020 on the M-11 route with backdoor access
- Recently the chargers were disabled and displayed anti-Putin/pro-Ukraine messages

Hacked electric car charging stations in Russia display 'Putin is a d*ckhead' and 'glory to Ukraine'

Fred Lambert - Feb. 28th 2022 10:13 am PT @FredericLambert



https://electrek.co/2022/02/28/hacked-electric-car-charging-stations-russia-displays-putin-dckhead-glory-to-ukraine/
https://www.dailymail.co.uk/news/article-10565697/Russian-electric-vehicle-chargers-hacked-display-message-supporting-Ukraine.html
https://jalopnik.com/russian-company-outsourced-the-main-components-in-ev-ch-1848603252

Maintenance and Internal Interfaces

Maintenance interfaces are common on EVSEs, including:

- Serial (e.g., RS485, RS232, serial over USB, etc.)
- Wi-Fi or Ethernet (e.g., SSH, Telnet, HTTP, etc.)
- Bluetooth
- Front panel/screen codes

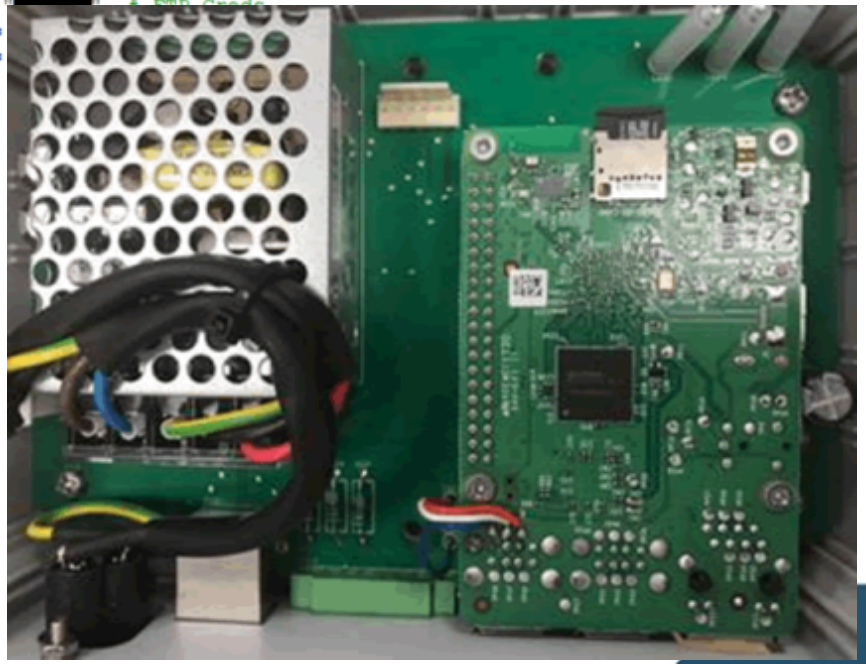
Fraunfofer found USB ports that would copy logs and configuration data including the OCPP server login and password, and authentication tokens from previous users.

Pen Test Partners noted issues with **secure storage** and **secure boot**.
Example exploit of eoHUB:

- Step 1: Remove the SD card
- Step 2: Inject root account
- Step 3: Boot device and SSH into system
- Step 4: Exfiltrate/modify anything of value
  - Full source code of device
  - FTP Credentials
  - SMTP Credentials
  - Cloud communication encryption/decryption keys


```
#### CONSTANTS ####
self.OFFLINE_MODE = False
self.CONFIG_FILE = '/boot/hub.ini'
self.FW_ADDED_CHKSUM = [redacted] # This charger firmware added the checksum into all packets
self.FILE_KEY = "[redacted]"  # As string for file encryption
self.CCS_ENC_SECRET_KEY = [redacted] # CCSys decrypt/encrypt Key
self.EO_FLASH_SYNC_ADDR = '[redacted]'  # USED TO GLOBALLY TELL UNITS TO RE-SYNC THEIR FLASHING
self.UPDATE_FOLDER = "update"  # Folder name for update
self.UPDATE_FILE_NAME = "update"  # name of update script
self.CONST_TERM_RESEND = 10  # Seconds untill a termination is being resent
self.CONST_TERM_FAILRE = 60  # Seconds till we think there is a problem with this message
self.CONST_TERM_SES_CHECK = 120  # Time untill sesssions are checked with server
self.CONST_CCS_FTP_SVR = "[redacted]"  # FTP Address for sending the log files
self.CONST_CCS_FTP_USR = "[redacted]"  # FTP Creds
self.CONST_CCS_FTP_PASS =
self.CONST_CCS_FTP_PORT =
```

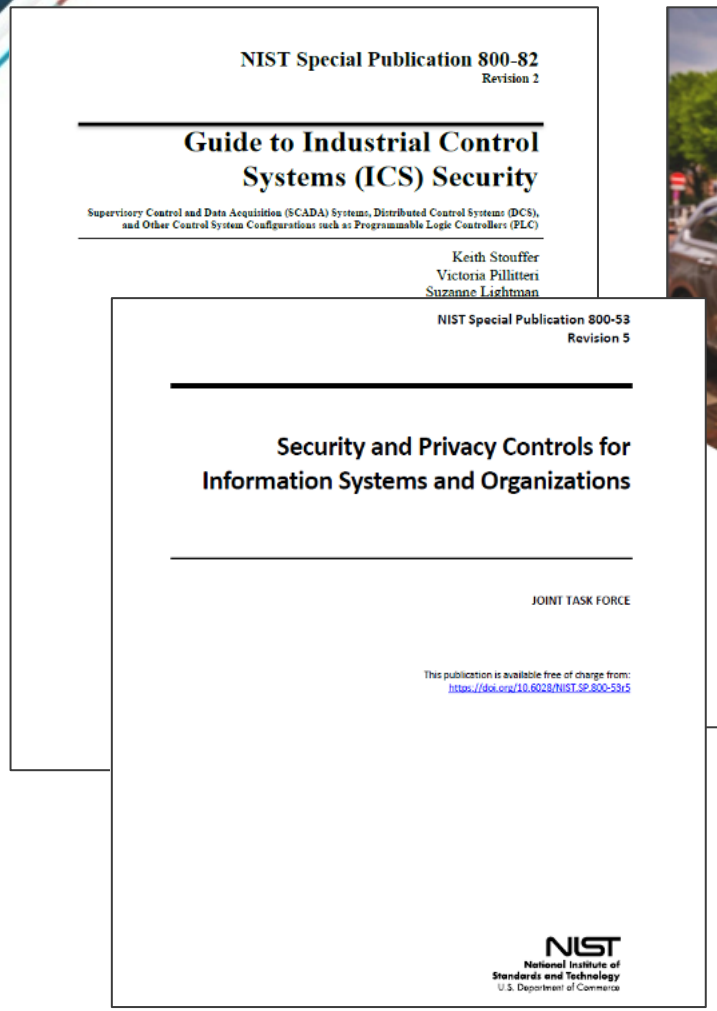
PEN TEST PARTNERS



- https://media.ccc.de/v/34c3-9092-ladeinfrastruktur_fur_elektroautos_ausbau_statt_sicherheit
- https://usa.kaspersky.com/blog/electric-cars-charging-problems/14357/
- https://www.pentestpartners.com/security-blog/pwning-a-smart-car-charger-building-a-botnet/
- https://www.pentestpartners.com/security-blog/smart-car-chargers-plug-n-play-for-hackers/

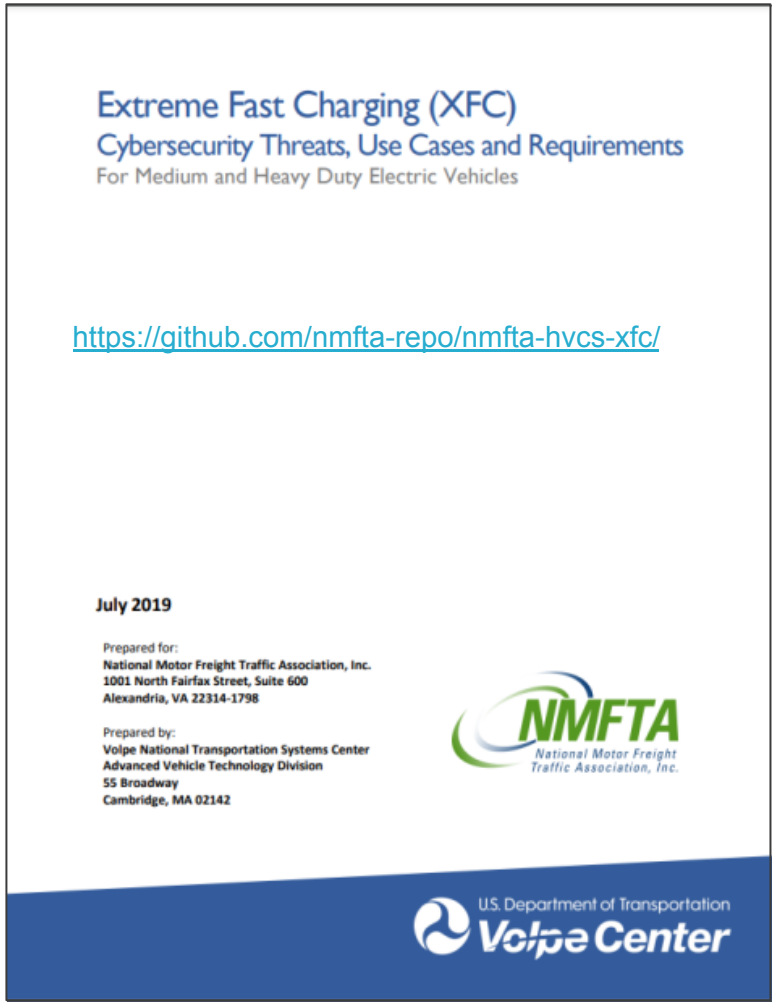
How can we mitigate these issues?

EVSE Cybersecurity Recommendations/Guidance/Defenses



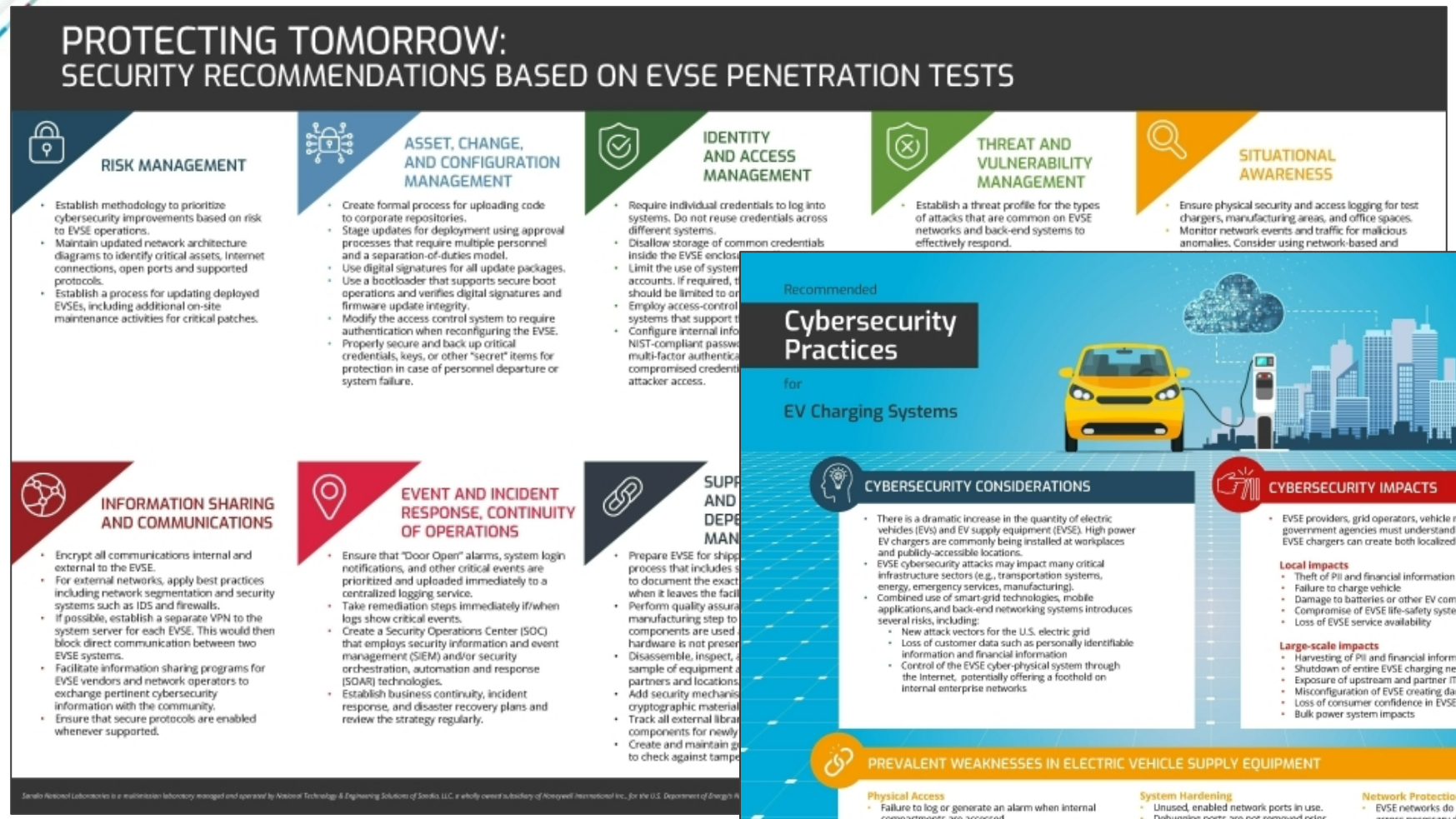
NIST Cybersecurity Best Practices

ElaadNL procurement requirements, test plans, and architecture for EVSEs



NMFTA/Volpe Center EVSE Requirements for medium and heavy duty charging

Sandia EVSE Cybersecurity Best Practices Infographic



- Guidance based on findings from hands-on assessments
- High-level view of the entire ecosystem in a single, concise document

https://www.researchgate.net/publication/344888849_Recommended_Cybersecurity_Practices_for_EV_Charging_Systems

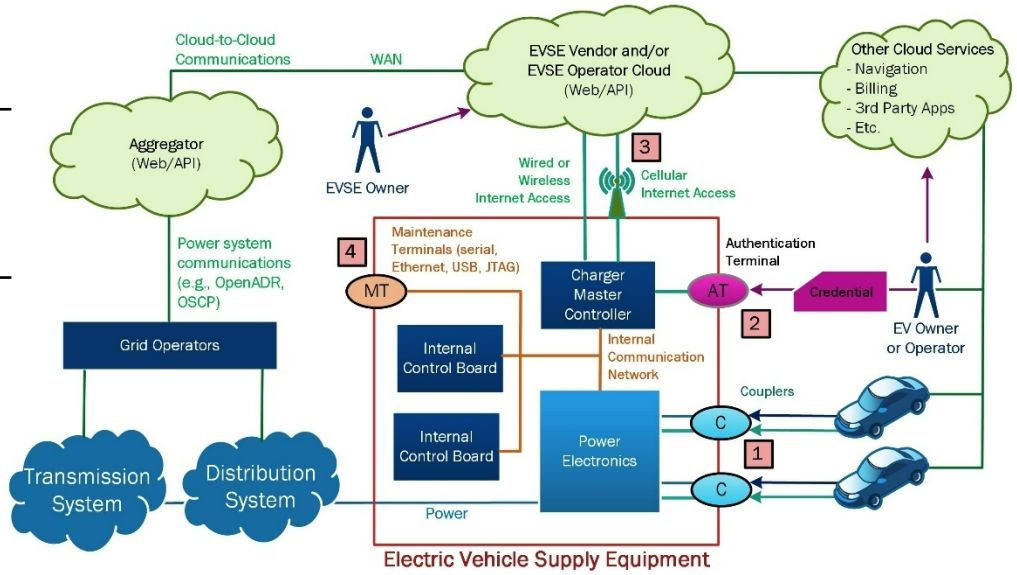
EVSE Cybersecurity Recommendations – Lots more out there!

Organization/Researchers	Cybersecurity Hardening Suggestions, Technologies, or Topics
U.S. DOT Volpe Center, 2019	Collection of XFC requirements: design, logging, cryptography, communication, assurance, hardening, resiliency, secure operation, etc.
Chan and Zhou, 2014	Cyber–physical challenge-response charging authentication
Sandia, 2021	Broad cyber recommendations for business and EVSE network & operations, EVSE physical and logical interfaces, and EVSE ecosystem.
NREL, 2019	Encrypt data-at-rest and data-in-flight, remove external ports, add tamper alarms, and certify cloud services with FedRAMP.
ElaadNL, 2016	Design, cryptography, communications, system hardening, resilience, access control, logging, product lifecycle, governance, assurance.
ElaadNL, 2019	Access control, cryptography, communications, physical/information, operational (backup, logging, vulnerability management) security.
Eekelen *et al.*, 2014	Recommendations for design, implementation, infrastructure, and incident issues; stronger authentication of customer identity; end-to-end encryption; add data-centric security and publish/subscribe middleware to OSCP
Baker & Martinovic, 2019	Prevent remote sideband CCS data extraction via electromagnetic shielding; improve PLC key distribution; add new SLAC initialization steps
Chan & Zhou, 2014	Add cyber–physical challenge-response mechanism for J1772 authentication
Vaidya & Mouftah, 2020	Employ ISO 15118 Multimodal and Multi-pass Authentication Mechanisms
INL, 2017 and 2018	Deploy intrusion detection systems to allow/block charging based on EV security profile
DigiCert, ChargePoint, and Eonti, 2019	Create certificate policy for all V2G PKI hierarchies, improve certificate revocation policies, create key management requirements, etc.
Fuchs *et al.*, 2019; Fuchs *et al.*, 2020	Use Security Module (SecMod) Protection Profile to evaluate the security functions of the ISO 15118 communication protocol
Lee *et al.*, 2014	Harden ISO 15118 with additional authentication mechanisms, improve message validity, and using a third-party auditor to thwart EV-EVSE collusion
Höfer *et al.*, 2013	Add protocol to ISO 15118 to provide greater privacy
Bao *et al.*, 2018	Add clock synchronization, EV OBC clocks within the EVSE, and mandatory TLS encryption to ISO 15118
Mültin, 2018	Move to PnC identification mechanisms to avoid the insecurity of RFID and other nearfield authorization technologies
Rubio *et al.*, 2018	Adding TLS profiles, endpoint security, and role-based access control (RBAC) security mechanisms to OCPP
Van Aubel *et al.*, 2019	Use extensions to ISO 15118, OCPP, and OCPI to provide secrecy and nonrepudiation at the in-dividual data field level
Vaidya & Mouftah, 2018	Use a role-based access control system on the OCPP Control Center server
INL, 2018	Use TLS, code signing, unique username/password combinations, improve mobile APIs, and securing sessions with a signed certificate
Moroson & Pop, 2017	Neural network trained to detect malicious OCPP traffic
Carlson, 2021	Monitor EV charger operations with intrusion detection framework
Gottumukkala *et al.*, 2019	Use secure-by-design principals, software security, hardware security, and tamper monitoring and resistance
Ghatikar, 2021	Secure Network Interface Card (S-NIC) with secure boot and tamper resistant technologies
Yang, *et al.*; 2011; Liu *et al.* 2014	Privacy-preserving technologies for V2G applications

There's a vibrant community of cyber researchers working to secure EV charging systems!

Research Needs – A Call to Arms!

	Interface	Research Areas
1	EV-to-EVSE	• Techniques to prevent loss or manipulation of charging communications via side-channel attacks. • Improved authentication and authorization mechanisms for EV and EVSE equipment, including those established with PKIs.
2	EV Operator	• New privacy-preserving authentication solutions for EVs and EV operators. • Improved EVSE credential, data, and PII storage. • Hardened and sanitized local web services.
3	EVSE Internet	• Communication solutions with end-to-end confidentiality, integrity, authentication, authorization, non-repudiation, and auditing. • Novel EVSE firmware update mechanisms that account for key/certificate provisioning and storage. • EVSE network-based intrusion detection and mitigation systems. • Cloud, website, and API security solutions that prevent manipulation or information disclosure with authentication on all endpoint operations.
4	EVSE Maintenance	• Host-based intrusion detection systems and tamper-resistant technologies for physical and logical access. • Device-level security features, including secure storage, secure bootloaders, and other software/hardware hardening technologies.

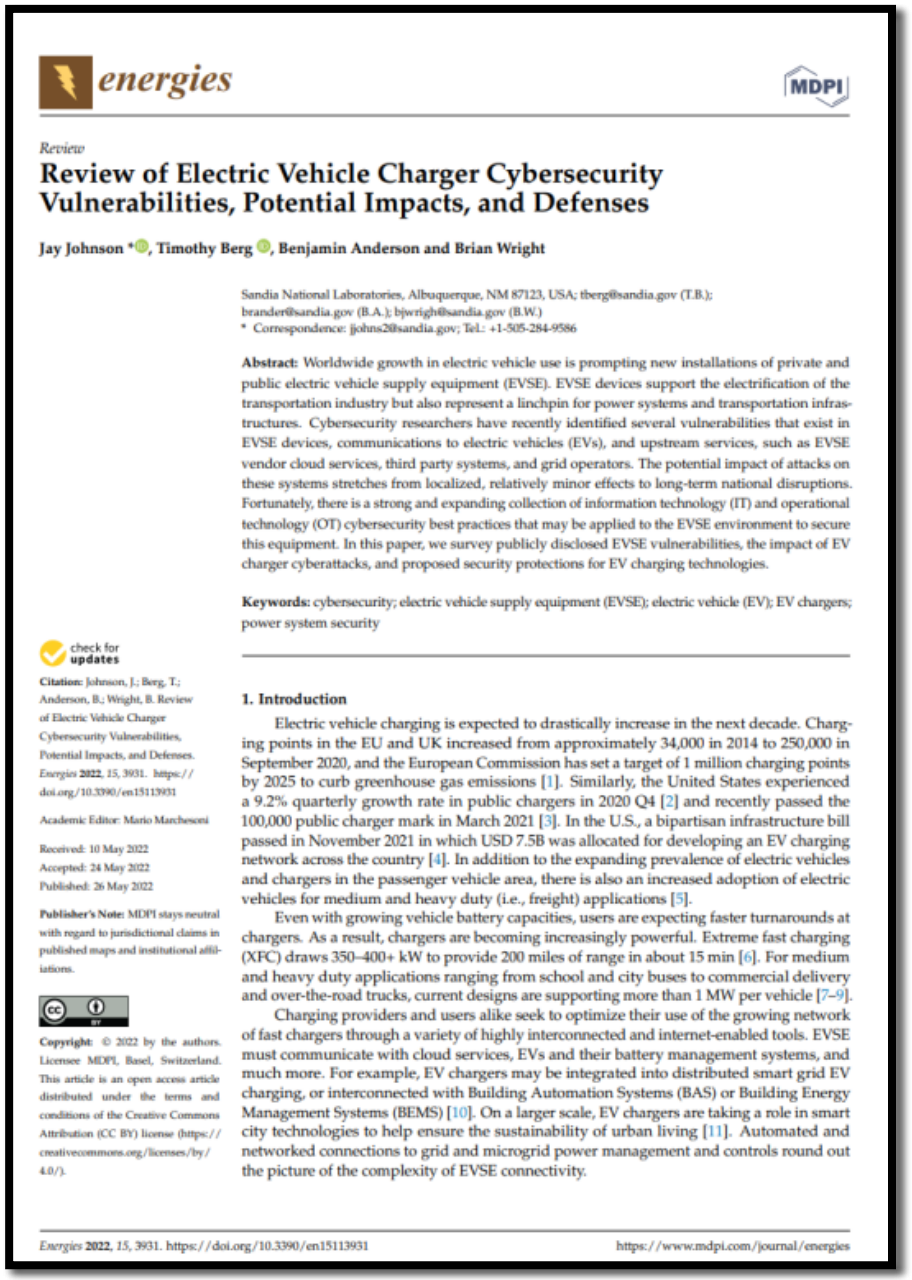


Shameless Plug

Publication covering information from this talk (and lots more!)

- Additional discussion of public EVSE vulnerabilities
- Survey of functional, financial, privacy, safety, and power system impacts from EVSE cyberattacks
- Security suggestions and other defensive solutions

J. Johnson, T. Berg, B. Anderson, and B. Wright, “Review of Electric Vehicle Charger Cybersecurity Vulnerabilities, Potential Impacts, and Defenses,” *Energies*, vol. 15, no. 11, p. 3931, May 2022, doi: 10.3390/en15113931.



energies

MDPI

Review

Review of Electric Vehicle Charger Cybersecurity Vulnerabilities, Potential Impacts, and Defenses

Jay Johnson *, Timothy Berg, Benjamin Anderson and Brian Wright

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Abstract: Worldwide growth in electric vehicle use is prompting new installations of private and public electric vehicle supply equipment (EVSE). EVSE devices support the electrification of the transportation industry but also represent a linchpin for power systems and transportation infrastructures. Cybersecurity researchers have recently identified several vulnerabilities that exist in EVSE devices, communications to electric vehicles (EVs), and upstream services, such as EVSE vendor cloud services, third party systems, and grid operators. The potential impact of attacks on these systems stretches from localized, relatively minor effects to long-term national disruptions. Fortunately, there is a strong and expanding collection of information technology (IT) and operational technology (OT) cybersecurity best practices that may be applied to the EVSE environment to secure this equipment. In this paper, we survey publicly disclosed EVSE vulnerabilities, the impact of EV charger cyberattacks, and proposed security protections for EV charging technologies.

Keywords: cybersecurity; electric vehicle supply equipment (EVSE); electric vehicle (EV); EV chargers; power system security

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1. Introduction

Electric vehicle charging is expected to drastically increase in the next decade. Charging points in the EU and UK increased from approximately 34,000 in 2014 to 250,000 in September 2020, and the European Commission has set a target of 1 million charging points by 2025 to curb greenhouse gas emissions [1]. Similarly, the United States experienced a 9.2% quarterly growth rate in public chargers in 2020 Q4 [2] and recently passed the 100,000 public charger mark in March 2021 [3]. In the U.S., a bipartisan infrastructure bill passed in November 2021 in which USD 7.5B was allocated for developing an EV charging network across the country [4]. In addition to the expanding prevalence of electric vehicles and chargers in the passenger vehicle area, there is also an increased adoption of electric vehicles for medium and heavy duty (i.e., freight) applications [5].

Even with growing vehicle battery capacities, users are expecting faster turnarounds at chargers. As a result, chargers are becoming increasingly powerful. Extreme fast charging (XFC) draws 350–400+ kW to provide 200 miles of range in about 15 min [6]. For medium and heavy duty applications ranging from school and city buses to commercial delivery and over-the-road trucks, current designs are supporting more than 1 MW per vehicle [7–9].

Charging providers and users alike seek to optimize their use of the growing network of fast chargers through a variety of highly interconnected and internet-enabled tools. EVSE must communicate with cloud services, EVs and their battery management systems, and much more. For example, EV chargers may be integrated into distributed smart grid EV charging, or interconnected with Building Automation Systems (BAS) or Building Energy Management Systems (BEMS) [10]. On a larger scale, EV chargers are taking a role in smart city technologies to help ensure the sustainability of urban living [11]. Automated and networked connections to grid and microgrid power management and controls round out the picture of the complexity of EVSE connectivity.

Conclusion

Cybersecurity researchers continue to identify EV charger vulnerabilities

- Part of a **continuous process of hardening charging infrastructure** against cyberattacks
- EVSE vendors should have **bug bounty programs** and support **responsible disclosure processes**
- EVSE vendors and 3rd parties should consider adopting **zero-trust principles** in addition to traditional perimeter defenses

Federal and state governments should **seek policies to improve the security of EVSE systems**

- National Electric Vehicle Infrastructure (NEVI) Formula Program adding cybersecurity requirements
- **Similar issues exist for the distributed energy resource (DER) industry** – there is a growing community addressing those issues (e.g., SunSpec/Sandia DER Cybersecurity Workgroup)

Comprehensive national cybersecurity approach must include:

- **Information sharing programs** in conjunction with EVSE/cloud **anomaly/intrusion detection systems**
- **Incident response strategies**, especially for coordinated/widespread attacks on grid infrastructure