The emerging future of EV charging: Widespread adoption of NACS technology in the United States

Introduction

For over 20 years, the designers and developers of Enphase EV Chargers have been pioneers in electric vehicle (EV) adoption and the expansion of EV charging infrastructure—first through ClipperCreek, and now through Enphase solutions for home and business.

As a leader in the industry and a provider of charging support for all North American EV makes and models, we continually survey the landscape of EV technology to ensure that Enphase solutions reliably serve as many EV owners and operators as possible.

Currently, one of the most notable trends in EV charging technology is the ongoing shift to North American Charging Standard (NACS) connectors. In this white paper, we examine what this means for EV drivers and the further growth of charging infrastructure, address the opportunities and challenges for the industry, and explore some of our own steps in response.

Table of content

1. Understanding NACS charging technology

An electric vehicle (EV) charging system based on proprietary equipment from Tesla, Inc., the North American Charging Standard (NACS) is playing a significant role in the rapid development of EV charging technology and infrastructure in the United States.

For over a decade, systems like NACS were informally known as 'Tesla plugs' or 'Tesla connectors,' used almost exclusively by Tesla's Level 2 wall connectors and Level 3 Superchargers, until Tesla rebranded, slightly modified, and opened the technology for use by other original equipment manufacturers (OEMs) in November 2022.[1] Tesla also released a series of technical documents, CAD files, and datasheets[2] detailing the technology's components, dimensions, and operations of the charging plug.

During the summer of 2023, many predominant auto and electric vehicle supply equipment (EVSE) manufacturers announced plans to utilize the NACS by 2025, poising the technology for widespread adoption in the latter half of the decade.

1.1 NACS vs. Combined Charging System (CCS) and CHAdeMO

Before Tesla opened the NACS design to other OEMs, EV and EVSE manufacturers utilized Combined Charging Systems (CCS) or CHAdeMO chargers to achieve the benefits of direct current (DC) fast charging.

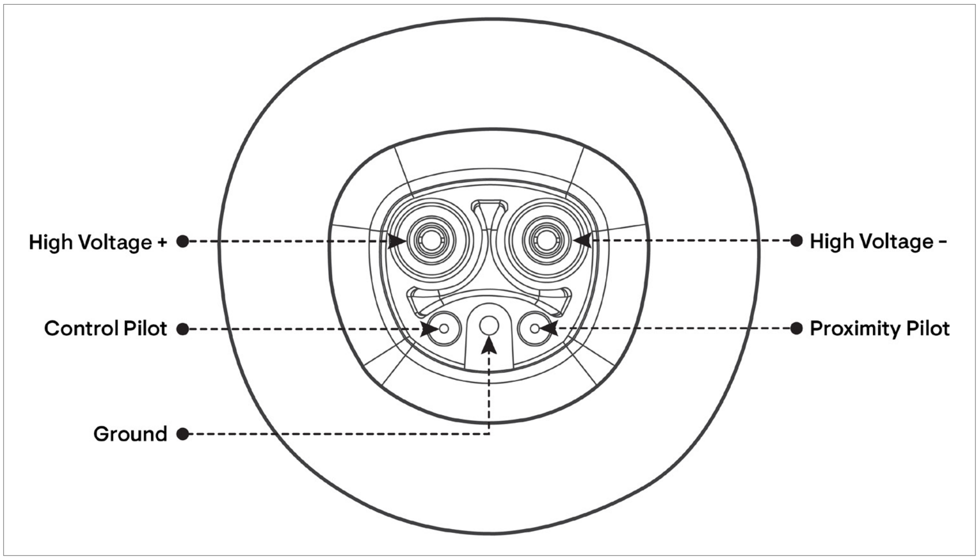
Charging Connectors	
Level	**Connector**
Level 1	SAE J1772
Level 2	SAE J1772
	NACS
DC Fast	CCS
	CHAdeMO
	NACS

Named for its combination of two EVSE technologies, the CCS combines a universal J1772 connector to deliver alternating current (AC) with a high-voltage extension to deliver direct current (DC) to an EV battery. Similar in capability to the NACS, but larger in size, the CCS essentially served as the charging standard for non-Telsa EVs in North America until the introduction of the NACS.

Separately, CHAdeMO connectors exclusively provide direct current fast charging (DCFC) and require an additional port for AC power. This is one of the primary reasons the technology has been nearly phased out by EV manufacturers as of 2024.

1.2 NACS components

The defining feature of a NACS system is its unique 5-pin layout, which allows AC and DC current to travel through the same pair of physical conductors or 'pins.' This layout enables the NACS design to be more compact than the CCS connector, which uses a separate set of pins for AC and DC charging.



The following table outlines the function of the NACS connector's five key components.

PIN	FUNCTION
High Voltage Positive (HV+)	When DC fast charging, the HV+ pin delivers positive DC voltage to the EV battery. During AC charging, the HV+ pin may be the sole line of electricity in a single-phase connection, or Line 1 in a split-phase connection.
High Voltage Negative (HV-)	Completing the circuit, the HV- pin provides the negative voltage necessary to enable DC fast charging. For AC charging, the HV- pin serves as Line 2 in a split-phase connection, or a neutral line in a single-phase connection.
Ground (G)	As a safety feature and reference point for system voltage, the ground pin connects an EV to the earth. In the event of a potential electrical fault such as a short circuit, the ground pin can safely absorb and isolate unstable current.
Control Pilot (CP)	The CP pin establishes the digital communication path between the EV and EVSE using pulse width modulation (PWM). The CP pin is used to detect EV compatibility, engage charging, and monitor power rates.
Proximity Pilot (PP)	Using a low-voltage signal, the PP pin determines when a valid physical connection has been established or terminated between the EV and EVSE. At the end of a charging session, the PP circuit is opened to stop the flow of electricity.

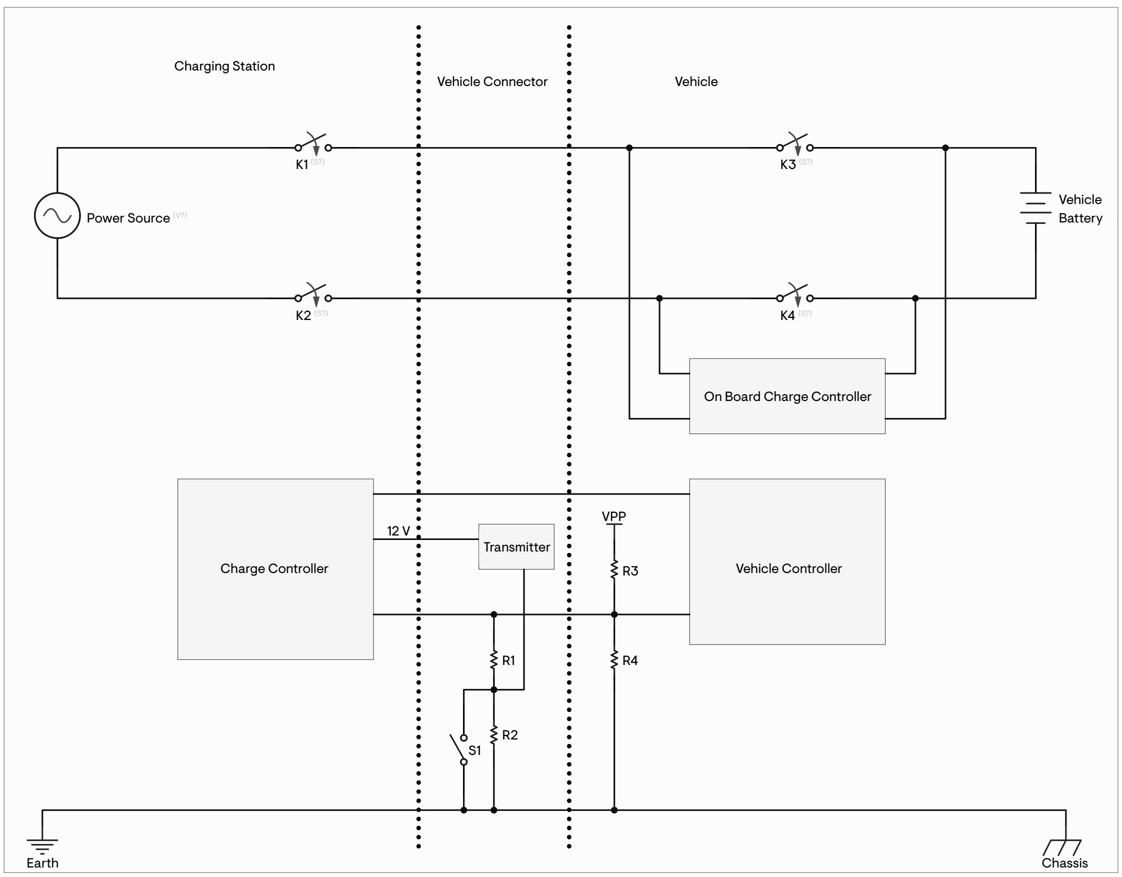
1.3 NACS charging process

Although a manual payment step may be necessary to initiate a session at a paid EV charger, the NACS charging process can be broken down into the following steps in both public and home settings:

1. **Initiating the charging session:** To begin charging with a NACS connector, access to the EV charging port must be opened. This can be accomplished in several ways depending on the vehicle type, such as a physical touch on the port door, a dashboard button, or by pressing the tactical switch on the connector handle to open the port once detected by the charger's proximity pilot.

2. **Inserting the connector:** Next, the NACS connector must be physically plugged into the vehicle's charging port. When the NACS connector is plugged into the EV, a parameter exchange and compatibility check are initiated to safely charge the battery with either AC or DC electricity.

3. **Monitoring and disengaging:** During the charging session, drivers can monitor charging progress remotely or from their vehicle. To terminate the charging session, pressing the button on the NACS connector disengages the lock and allows it to be safely removed from the vehicle port. For many models, the vehicle must be unlocked to physically remove the connector from the charge port.

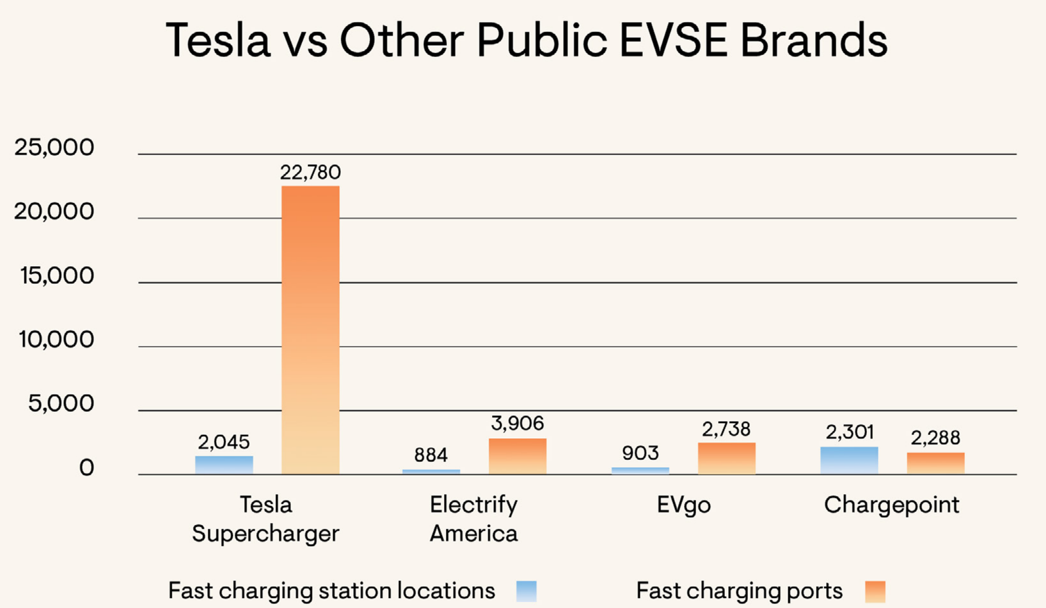


2. Advantages of NACS charging

To advance and support EV adoption in the U.S., the NACS presents many advantages over other charging technologies.

2.1 Existing NACS infrastructure

In 2023, Tesla charging stations made up the most prominent and reliable EVSE network in the U.S. by a large margin.[3] Equipped with NACS-compatible connectors, Tesla's public charging stations have a reported uptime of over 99%.[4] Comparatively, a 2022 study found that one out of every four CCS chargers in the Bay Area was non-functional.[5]



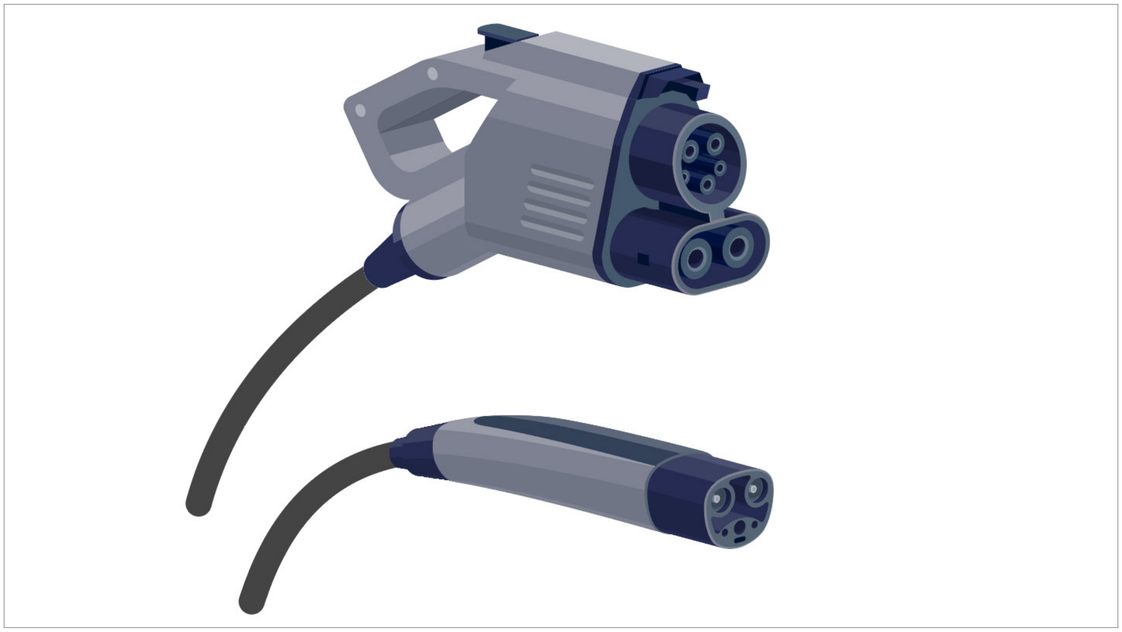
Source data as of November 30, 2023

The ease of public access to Tesla's charging stations was cited by both GM and Ford as the primary motivation for adopting NACS as an EV charging standard.[27] While Tesla has voiced intentions to eventually open its chargers to all compatible EV models,[6] Ford and General Motors (GM) drivers will be the first to gain access in 2024.[7]

To learn more about NACS infrastructure in the U.S., see Section 5.

2.2 Compact, user-friendly, and cost-saving design

The compact size and design of the NACS connector gives the technology a distinct physical advantage over CCS connectors.[8]



On an EV, a NACS port also occupies less space than its CCS equivalent, allowing OEMs slightly more flexibility in vehicle design and port placement. With less material used, early speculations indicate that NACS equipment may incur fewer costs to manufacture than CCS systems.[9] While there is still little real-world data to confirm this, even a small reduction in manufacturing costs could become significant for major brands deploying hundreds of thousands of EVs annually to meet consumer demand.[10]

2.3 Faster charging rates and reduced charging times

Tesla's initial claim[11] that NACS is "twice as powerful as [the] Combined Charging System (CCS)" may be misleading, as there is no definitive evidence that suggests any difference between the two connector shapes has any significant influence on total energy capacity or charging speed.

While early, pre-standardization tests indicate that NACS can deliver superior charging efficiency,[12] the time and power used in any EV charging session will always be limited by many factors beyond the connector itself, including the battery's state of charge, the vehicle's maximum power intake, and the property's transformer capacity or electrical limitations.

2.4 Universal compatibility and grid integration

The NACS has an electrical and mechanical agnostic interface[1] that enables the same Power Line Communication (PLC) protocols (ISO 15118 and DIN 70121) as the CCS system. With the use of an adapter, this allows for near-universal compatibility in charging all EV models on the road today.[13] These protocols also enable opportunities for bidirectional vehicle-to-load (V2L), vehicle-to-grid (V2G), and vehicle-to-home (V2H) charging.

3. Addressing concerns: Potential cons of NACS adoption

During the mid-2020s, OEMs and EV drivers may face several transitional challenges as NACS is more widely adopted. In addition to the potential setbacks outlined below, it is also important to note that NACS adoption alone will not eliminate all the challenges associated with modern EVSE infrastructure.

For example, existing Tesla charging stations have a great reported uptime because they are vertically integrated and well-maintained,[4] and not simply because of the connector type used. Conversely, even with NACS, an unmaintained public EVSE station may still be prone to screen issues, network connectivity problems, or payment system failures.[5]

3.1 Achieving true standardization

Despite its name, the North American Charging Standard (NACS) had not yet been reviewed by any external standards organizations when Tesla opened the proprietary technology to other OEMs. Without any third-party processes, skeptics have raised potential safety and data privacy[14] concerns for non-Tesla vehicles charging with the NACS system.

To verify its safety and practicality, the Society of Automotive Engineers (SAE), the same standards body that approved the CCS,[15] announced that it would expedite the standardization process for the NACS.[16] Entitled SAE J3400, the NACS standard was labeled as a work in progress (WIP) on the organization's website as of early 2024. While the NACS is still technically proprietary to Tesla, the SAE J3400 will become an open standard for all industry stakeholders to use and improve.[13]

3.2 Challenges at existing Tesla charging stations

With short cables to prevent abuse, Tesla's public charging stations have been designed specifically to accommodate Tesla vehicles, typically leaving little room for flexibility in where a driver can park and charge. For non-Tesla vehicles with charging ports in places other than the taillight assembly, this may make existing NACS infrastructure difficult to utilize, especially if the cables cannot physically reach an EV's charging port.[17]

While the NACS system is designed for near-universal software compatibility, it is also important to note that until recently, all of Tesla's Supercharging stations utilized the company's single-wire CAN signaling to provide EVSE to EV communication. With NACS systems using ISO 15118 and DIN 70121 PLC protocols, existing Tesla charging stations may need to be upgraded to allow seamless NACS charging without an adapter.

3.3 Supply chain development

With most major OEMs planning to adopt the NACS by 2025, the U.S. auto industry has effectively given itself less than two years to adjust to the new standard. In pivoting away from CCS chargers, significant supply chain adjustments will be necessary for EV and EVSE manufacturers to produce NACS ports, connectors, and cables to meet this timeline.[14]

3.4 Infrastructure requirements and project costs

When installing new EV chargers, infrastructure requirements and project costs increase dramatically when accommodating high-voltage systems like the NACS. As today's high-capacity 350 kW EV charging stations can incur total installation costs near $140,000 each,[18] NACS systems designed to deliver larger loads may be even more expensive to develop and untap their full potential.

When retrofitting an existing charger to become NACS-compatible as a homeowner or public charging station operator, transitional costs are not as substantial if no other additional electrical upgrades are required. With several new retrofit-ready products and services entering the market, EVSE owners replacing an existing cable and connector with NACS technology can expect estimated conversion costs between $200 and $500 per charger for the necessary hardware and project expenses.

To learn more about how the potential challenges of NACS standardization are being overcome, see Section 6.

4. The role of EV manufacturers in NACS adoption

Due to Tesla's popularity, NACS-based vehicles in the U.S. outnumbered CCS vehicles two-to-one[1] in late 2022. After start-up Aptera Motors[20] was the first non-Tesla company to publicize intentions of NACS adoption, industry giants Ford and GM announced they would manufacture EVs with NACS ports beginning in 2024 and 2025, respectively. Together, Tesla, Ford, and GM make up nearly 75% of the U.S. EV market.[21]

While Volkswagen was still considering adoption as of October 2023, Hyundai Motor Group, Fisker, Honda, Mercedes-Benz, Nissan, Polestar, Rivian, and Volvo have all announced plans to use the NACS as a standard EV connector by 2025, and that adapters will be made available to customers with their CCS-equipped vehicles.[22]

4.1 Importance of standardization in EV charging technology

With EV adoption rates dramatically outpacing the development of EVSE infrastructure in the United States,[23] standardizing EV charging technology can help maximize the use of limited public resources to serve a wider pool of drivers. If NACS were to become the lone standard, this would result in better overall ownership experiences for EV drivers, including less complicated purchasing decisions[19] for new vehicles and home charging equipment.

Critically, compatibility with Tesla and CCS-equipped vehicles makes NACS standardization easy for most EV drivers already on the road today. This includes 97.6% of new EV models in 2023,[24] barring only the Nissan LEAF, which is equipped with the CHAdeMO system and will be phased out by 2026.[26]

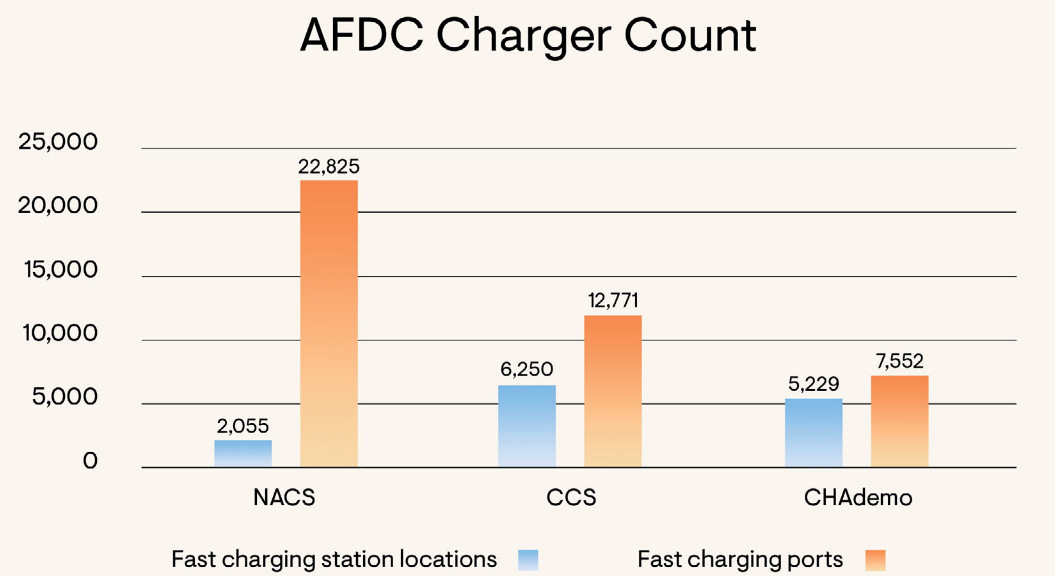
4.2 Incentives for EV manufacturers to adopt NACS

By manufacturing future EV models with NACS ports, OEMs can reduce the likelihood of slower charging rates caused by adapters[27] and create seamless charging experiences for their customers using either Tesla equipment or a NACS charger at home.[28] As the NACS uses the same communication protocols as CCS systems, most OEMs should be able to adopt the technology without substantial battery management software overhauls.[8]

5. NACS charging infrastructure in the U.S.

A 2023 report from the Department of Energy (DOE) Alternative Fuels Data Center (AFDC) found there were 1,803 Tesla Supercharging stations in the U.S., for a total of 19,463 chargers.[29] Over a decade in the making, this network of Tesla-brand EV stations features NACS-compatible charging opportunities every 70 to 120 miles along nearly every interstate highway in the country.[30]

Compared to the 10,471 CCS and 6,930 CHAdeMO chargers spread across 5,240 and 4,790 EV charging stations respectively, there are more public-facing NACS chargers in the U.S. than CCS and CHAdeMO chargers combined, and at a significantly higher charger-per-station count.[29]



Source data as of November 30, 2023

Regionally, NACS charging station frequency is greater in areas with denser populations and higher EV adoption rates, such as Miami, San Diego, and Las Vegas.[31] In rural areas, NACS infrastructure is typically more centralized, such as Tesla's 100-stall charging station near Barstow, California.[32]

In the summer of 2023, California led the nation with 363 Telsa Supercharging stations (nearly 20% of the U.S. total) statewide, followed by Florida (7%), Texas (7%), New York (4%), Pennsylvania (4%), Virginia (3%), and New Jersey (3%).[31]

5.1 The transition to the NACS as an industry standard

Supporting NACS standardization alongside EV OEMs, many charging station operators and EVSE manufacturers have announced intentions to add the NACS connector to existing and future EV chargers. This includes Electrify America, the second-largest U.S. fast charging station operator after Tesla.[30]

With NACS as the future standard, the transition away from CCS infrastructure will take several forms, including on-site adapters as well as charging stations that host both connectors like Tesla's Magic Dock Superchargers in New York, California, Texas,[33] Utah, Colorado, Michigan, and Washington.[25] In October 2023, no OEMs have publicized plans to introduce a CHAdeMO to NACS adapter.

5.2 NACS charging technology from Enphase

In support of NACS standardization, Enphase Energy will begin to manufacture and sell Level 2 EV charging stations with NACS connectors in 2024. Guaranteed with the same performance and durability as existing Enphase EV Chargers, NACS-equipped chargers from Enphase will be offered in a variety of power capabilities designed to enable the most efficient charging solutions for any EV, whether at home, work, or other locations.

6. Overcoming challenges: the path to NACS standardization

For Tesla's propriety technology to become the future EVSE standard in the U.S., the NACS has had considerable support from both federal and state governments as well as large private industry players. When the SAE publicized its plans[16] to expedite NACS standardization, the organization thanked the Joint Office of Energy and Transportation for being "instrumental in fostering the SAE-Tesla partnership and expediting plans to standardize NACS."

On the same day, the White House described the announcement as "a win for the EV charging industry and a win for all EV drivers," also mentioning that the Joint Office of Energy and Transportation is developing an EV-Charging Analytics Reporting Tool (EV-ChART) to centralize and standardize all EV charger data reporting in the U.S.[34]

6.1 Policy initiatives and governmental support to accelerate NACS adoption

Although the White House previously lobbied for CCS connectors to be the national standard,[35] the US Department of Transportation's (DOT) Federal Highway Administration (FHWA) made a small adjustment to its National Electric Vehicle Infrastructure (NEVI) initiative to help support NACS adoption.

The program, which can fund up to 80% of the costs of eligible EV charging station projects,[36] can now be used to finance NACS-equipped systems,[37] "so long as each DCFC charging port is capable of charging a CCS-compliant vehicle." In addition to funding new charging station projects, the FHWA has also made $100 million available[38] to "repair and replace existing but non-operational EV charging infrastructure," which can include NACS upgrades.

In July 2023, Kentucky became the first state to mandate that federally funded EV charging stations include NACS connectors[39] as well as the required CCS connectors. This was followed by similar policies passed in Texas[40] and introduced (but not implemented as of March 2024) in Washington.[41]

6.2 Collaboration between industry stakeholders to promote NACS infrastructure growth

To grow and improve EVSE infrastructure in the US, collaboration in place of competition between major industry stakeholders is helping shape a better future for EV drivers and manufacturers alike. In 2023, the Joint Office of Energy and Transportation created the National Charging Experience Consortium (ChargeX) to address common EVSE infrastructure challenges such as payment processing, vehicle-charger communication, and diagnostic data sharing.[34]

Led by the Argonne National Laboratory, the Idaho National Laboratory, and the National Renewable Energy Laboratory, there are over 30 organizations[42] participating in ChargeX, including utilities, universities, and public supporters of NACS standardization such as Tesla, GM, Ford, Electrify America, and the Charging Interface Initiative (CharIN) Association.[43]

7. Outlook and takeaways

Looking towards the future, it appears that NACS and CCS connectors will coexist in the North American EVSE market for several years, in a relationship that can be compared to the various types of USB ports and adapters used to charge small electronics.

Ultimately, however, standardizing and unifying EV charging technology in the U.S. will result in less confusion, less charge anxiety, and simpler buying decisions for drivers, while OEMs will have opportunities to reduce manufacturing costs through more effective use of resources. With its compact design, compatibility with existing infrastructure, and strong industry support, NACS technology will soon eclipse CCS demand and become widely recognized as the standard for EV charging in the U.S.

While it is unclear whether J1772 and CCS chargers will phase out of the market entirely, universal compatibility with NACS technology will be critical to help current EV drivers access more charging equipment, regardless of vehicle brand. To accomplish universal compatibility, adapters from EV manufacturers, dually compatible public charging stations like Tesla's Magic Dock, and NACS-equipped EV charging stations, including those from Enphase, will help accelerate this transition.

Key Takeaways:

- The North American Charging Standard (NACS) will likely become the standard technology for high-power AC and DC EV charging in the United States.
- As of early 2024, the Society of Automotive Engineers (SAE) is working to standardize the NACS to ensure its safety and reliability for all EV and EVSE brands.
- Most North American EV manufacturers plan to adopt NACS systems by 2025, granting their customers access to a wider and more reliable network of existing public EV charging stations.
- NACS and CCS connector compatibly can help 97.6% of new EVs in 2023 access over 81% of existing U.S. public DC fast charging ports.
- NACS adoption will present transitional challenges for some EV and EVSE OEMs, as they may be required to make design, hardware, software, or supply chain updates for new products and retrofitting efforts.
- While NACS connectors do not solve many of the common issues EV drivers experience at public charging stations today, significant collaboration between industry stakeholders may improve the reliability of EV infrastructure in the U.S. over the decade to come.

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9. Acronym glossary

- **AC (alternating current):** Alternating current is the most common form of electricity used to power homes and businesses through typical wall outlets. Easily transmitted over long distances, AC is named for its ability to flow in alternating directions.

- **CCS (Combined Charging System):** Also known as the 'SAE J1772 combo,' the Combined Charging System was the standard EV charging system utilized by most non-Tesla EV manufacturers in the United States prior to the introduction of the NACS. CCS chargers allow for both alternating current (AC) and direct current (DC) charging.

- **CHAdeMO (Charge de Move):** Popularized in Japanese electric vehicles like the Nissan LEAF, the CHAdeMO is a DC fast charging system found in the United States and all over the world.

- **DC (direct current):** Unlike alternating current, direct current is a form of electricity that can only move in one direction, such as from an EV charger to an EV battery.

- **DCFC (direct current fast charging):** Direct current fast charging is a rapid EV charging technology sometimes referred to as Level 3 charging. DCFC can add hundreds of miles of range to an EV battery within 30 minutes.

- **EV (electric vehicle):** By definition, an electric vehicle may be any vehicle that is completely or partially powered by an electric motor. Today, the term EV is generally more associated with battery electric vehicles (BEVs) but may also refer to plug-in hybrid electric vehicles (PHEVs).

- **EVSE (electric vehicle supply equipment):** Often called charging stations, charging docks, or chargers, the term 'electric vehicle supply equipment' encapsulates any device, hardware, or infrastructure that allows EV drivers to charge their batteries.

- **FHWA (Federal Highway Administration):** The Federal Highway Administration is a division of the U.S. Department of Transportation that oversees U.S. highways and supports state governments with related planning, construction, and maintenance.

- **ISO (International Organization for Standardization):** Ensuring the quality, safety, and efficiency of several thousand global products and services, the International Organization for Standardization is a well-respected non-governmental organization that combines standards bodies from over 100 countries. In EV charging, the group's standard ISO 15118 describes a communication protocol between EVs and EVSE.

- **J1772 (J Plug):** The SAE J1772, also known as the 'Type 1 plug' or 'J plug' was the standard Level 1 and Level 2 EV charging connector for non-Tesla vehicles in the U.S. prior to NACS standardization. The J1772 plug supports a wide range of AC charging rates for EVs, and combined with DC charging pins, creates the CCS connector.

- **kW (kilowatt) and kWh (kilowatt-hour):** A kilowatt is a unit of power equal to 1,000 watts. A kilowatt-hour is a unit of energy use, measured in kilowatts per hour. Like consumption on an electricity bill, the capacity of an EV battery is measured in kWh.

- **NACS (North American Charging Standard):** The North American Charging Standard is a proprietary EV charging system designed to facilitate fast, efficient, and user-friendly EV charging.

- **OEM (original equipment manufacturer):** An original equipment manufacturer is a company that produces parts or equipment, such as Tesla or Enphase.

- **SAE (Society of Automotive Engineers):** The SAE is a U.S.-based global organization that develops and publishes standards for several industries including aerospace and automotive. As of early 2024, the NACS is under review by the SAE as SAE J3400.