State-of-the-Art in Electric Vehicle Charging Infrastructure

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***Abstract* — The international introduction of electric vehicles (EVs) will see a change in private passenger car usage, operation and management. There are many stakeholders, but currently it appears that the automotive industry is focused on EV manufacture, governments and policy makers have highlighted the potential environmental and job creation opportunities while the electricity sector is preparing for an additional electrical load on the grid system. If the deployment of EVs is to be successful the introduction of international EV standards, universal charging hardware infrastructure, associated universal peripherals and user-friendly software on public and private property is necessary. The focus of this paper is to establish the state-of-the-art in EV charging infrastructure, which includes a review of existing and proposed international standards, best practice and guidelines under consideration or recommendation.**

Keywords – electric vehicles, charging infrastructure, charging stations, guidelines, standards, transport

I. INTRODUCTION

The successful deployment of electric vehicles (EVs) over the next decade is connected to the introduction of internationally agreed EV standards, universal charging hardware infrastructure, associated universal peripherals and user-friendly software on public and private property. A number of workgroups have been formed by key organizations such as the International Energy Agency (IEA), the Society for Automobile Engineers (SAE) and the Institute of Electrical and Electronic Engineers (IEEE).

There are a number of economic and environmental benefits to the introduction of EVs. EVs have been identified as an opportunity to generate employment in research and development (R&D), manufacturing and deployment of EV infrastructure during this current global economic recession. EVs are also presented as an opportunity to reduce fossil fuel dependency and integrate renewable energy sources (RES), which should result in a better security of energy supply by reducing oil imports and a reduction in greenhouse gas (GHG) emissions and localized air pollution and noise levels. Furthermore GHG emissions are linked to global warming, whereas localized air and noise pollution can affect human health.

A number of countries including some European Union (EU) member states, Japan, South Korea, Canada, China, Israel and the United States of America (USA) have established EV targets, policies and plans in order to succeed in deploying EVs. Table 1 lists some internal government policies and targets.

Country	Targets
Austria	2020: 100,000 EVs deployed[1]
Australia	2012: first cars on road, 2018: mass deployment, 2050: up to 65% of car stock[2]
Canada	2018: 500,000 EVs deployed[3]
China	2011: 500000 annual production of EVs[4]
Denmark	2020:200,000 EVs [5]
France	2020: 2,000,000 EVs[6]
Germany	2020: 1,000,000 EVs deployed[7]
Ireland	2020: 10% EV market share[8]
Israel	2011: 40,000 EVs, 2012: 40,000 to 100,000 EVs annually[9]
Japan	2020: 50% market share of next generation vehicles[10]
New Zealand	2020: 5% market share, 2040: 60% market share[11]
Spain	2014: 1,000,000 EVs deployed[12]
Sweden	2020: 600,000 EVs deployed[13]
United Kingdom	No target figures, but policy to support EVs[14]
USA	2015: 1,000,000 PHEV stock[15]

1 http://www.iea-retd.org/files/RETRANS100128%20Schauer.pdf
2 http://australia.betterplace.com/assets/pdf/Better_Place_Australia_energy_white_paper-doc.pdf
3 http://www.evtrm.gc.ca/pdfs/E-design_09_0581_electric_vehicle_e.pdf
4 http://www.nytimes.com/2009/04/02/business/global/02electric.html
5 http://www.ens.dk/en-US/Sider/forside.aspx
6 http://www.physorg.com/news173639548.html
7 http://www.evworld.com/news.cfm?newsid=23301
8 http://www.dcenr.gov.ie/Press+Releases/2008/Government+announces+plans+for+the+electrification+of+Irish+motoring.htm
9 http://www.betterplace.com/
10 http://www.autosavant.com/2008/08/27/japan-charges-ahead-with-electric-cars/
11 http://www.msnbc.msn.com/id/21246592/
12 http://uk.reuters.com/article/idUKARO04096020080730
13 http://www.powercircle.org/en/display/Projects/swedish-electric-mobility-initative.aspx
14 http://www.dft.gov.uk/pgr/scienceresearch/technology/lowcarbonelecvehicles/
15 http://www.businessweek.com/technology/content/jun2010/tc2010063_322564.htm

TABLE I. SOME INTERNATIONAL EV TARGET OBJECTIVES

The focus of this paper is to establish the state-of-the-art in EV charging infrastructure. A list of existing and proposed international standards, best practice and guidelines is presented.

II. RELEVANCE & ROLE OF STANDARDIZATION

In the next decade the automobile industry and the electricity sector will undergo a series of evolutionary changes. Reference [1] examines this EV roadmap. New players will emerge and only the best or most fit for purpose technologies, companies and ideas will survive. Traditionally R&D in the automobile industry is very secretive because of strong competition, particularly in relation to the internal combustion engine (ICE). Automobile standards and best practice have developed over time, initially to improve safety to acceptable low injury and fatality rates, to avoid litigation

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and costly recalls, next during the oil crisis of the seventies the Europeans and the Asians particularly became very energy conscious so manufacturers developed more efficient ICE, unlike in North America where oil was cheaper at the pump and then in the eighties air pollution and more recently GHG emissions resulted in tougher government standards to reduce ICE emissions.

The drive to electrify transport will result in countries forming new trading alliances and partnerships to ensure the success of their technology. Standards may be used as tools in countries gaining a competitive advantage. The addition of new players and the changing role of existing players such as battery manufacturers, smart grid developers, electricity distribution companies, electricity regulators, utility companies and the electricity retail sector will see a massive change in the hitherto status quo of car manufacturing. The electricity sector is a different beast to the automobile industry with its own set of standards and regulations, which vary hugely from country to country and even within a country. Electricity companies have gone and are still going through a period of deregulation and market liberalization. In some countries certain utilities still have a dominant market position. The automobile industry has operated in a very competitive first to market environment. The marriage of these two very different sectors may see strange scenarios.

What is the ultimate goal of the electrification of transport? Is it to truly reduce GHG emissions or just reduce them and move them from the transport sector, which is a non-emissions trading scheme (Non-ETS) sector to the electricity sector, which is an ETS sector? Is it to re-invigorate the automobile industry and increase employment? Governments are under pressure to achieve results. In order to measure and quantify the results, energy efficiency from the grid-to-the-battery and from the battery-to-the-wheel, driving performance and overall net reduction in GHG emissions under different driving conditions using an international standard test regime must be agreed. Studies have been carried out to estimate benefits, but it is difficult to compare them as like the ICE, no two EVs are the same and no two power systems are the same. Reference [2] provides a detailed review of over 40 studies carried out in the USA to examine the effects of EVs on well-to-wheel emissions. Other recent articles study potential GHG emissions reductions from EVs include References [3 - 8].

Unfortunately as global economies are in recession and car sales have slumped, the car manufacturers look like the sector with the weaker hand and the most to lose, whereas electricity is a necessary commodity. It is suggested that the electricity sector is the stronger player in this 'EVlotion'. So perhaps unlike the automobile industries traditional reaction to events to mitigate costs and recalls, the rigid approach of the electricity sector because of the nature of power may result in standardization taking more of a front seat. Either way the 'EVlotion', will make for a very interesting 10 years for the engineers involved. In October of 2009 European electricity companies called for the standardization of EV charging infrastructure and pledged to apply pre-standards [9].

III. EV STANDARDS

The main centre of activity in standardization development appears to be in USA and Japan with slower progress in the EU. References [10 – 12] discuss EV technology development. Table 2 provides details of some relevant SAE and the American National Standards Institute (ANSI) EV standards and their status.

Standard	Status
NFPA 70 NEC/ANSI, Article 625 – Electric Vehicle Charging Equipment	Published January 1996, WIP January 2011
SAE J-1634: Electric Vehicle Energy Consumption and Range Test	Issued and cancelled October 2002
SAE J-1715: Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology	Original issued April 1994, revised February 2008 & WIP August 2009
SAE J-1766: Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing	Issued February 2005, revised April 2005
SAE J-1772: SAE Electric Vehicle Conductive Charge Coupler	Issued October 1996, revised November 2001 & a WIP 2009
SAE J-1773: SAE Electric Vehicle Inductively-Coupled Charging	Issued January 1995, reissued November 1999 & reaffirmed May 1995
SAE J-1797: Recommended Practice for Packaging of Electric Vehicle Battery Modules	Issued January 1997, and reaffirmed June 2008
SAE J-1798: Recommended Practice for Performance Rating of Electric Vehicle Battery Modules	Issued January 1997, reaffirmed July 2008
SAE J-2288: Life Cycle Testing of Electric Vehicle Battery Modules	Issued January 1997, reaffirmed June 2008
SAE J-2293 Part 1: Energy Transfer System for EV Part 1: Functional Requirements and System Architecture	Issued March 1997, reaffirmed July 2008
SAE J-2293 Part 2: Energy Transfer System for EV Part 2: Communications Requirements and Network Architecture	Issued May 1997, reaffirmed July 2008
SAE J-2380: Vibration Testing of Electric Vehicle Batteries	Issued January 1998 & revised March 2009
SAE J-2464: Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing	Issued March 1999, WIP August 2009
SAE J-2836 Part 1: Use Cases for Communications between Plug-In Vehicles and the Utility Grid	WIP April 2009
SAE J-2836 Part 2: Use Cases for Communications between Plug-In Vehicles and the Supply Equipment (EVSE)	WIP February 2009
SAE J-2836 part 3: Use Cases for Communications between Plug-In Vehicles and the Utility grid for Reverse Flow	WIP February 2009
SAE J-2841: Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using 2001 U.S. DOT National Household Travel Survey Data	WIP March 2009
SAE J-2847 Part 1: Communications between Plug-In Vehicles and the Utility Grid	WIP April 2009
SAE J-2847 Part 2: Communication between Plug-in Vehicles and the Supply Equipment (EVSE)	WIP no document available
SAE J-2847 Part 3: Communication between Plug-in Vehicles and the Utility Grid for Reverse Power Flow	WIP no document available
SAE J-2894 Part 1: Power Quality Requirements for Plug-In Vehicle Chargers - Requirements	WIP no document available
SAE J-2894 Part 2: Power Quality Requirements for Plug-In Vehicle Chargers - Test Methods	WIP no document available
SAE J-2908: Power Rating Method for Hybrid-Electric and Battery Electric Vehicle Propulsion	WIP no document available

TABLE II. SAE STANDARDS

Table 3 provides details of some relevant Deutsches Institut für Normung e. V. (DIN) EV standards and their status.

Standard	Status
DIN V VDE V 0510-11 (VDE V 0510-11) Safety requirements for secondary batteries and battery installations - Part 11: Safety requirements for secondary lithium batteries for hybrid vehicles and mobile applications	Published
DIN 43538 Monobloc batteries for electric vehicles; low maintenance types, rated capacities, main dimensions	

TABLE III. DIN STANDARDS

Table 4 provides details of some relevant International Standards Organisation (ISO) EV standards and their status.

Standard	Status
ISO 6469-1:2009 Electrically propelled road vehicles - Safety specifications - Part 1: On-board rechargeable energy storage system (RESS)	Published October 2009
ISO 6469-2:2009 Electrically propelled road vehicles - Safety specifications - Part 2: Vehicle operational safety means and protection against failures	Published October 2009
ISO 6469-3:2001 Electric road vehicles - Safety specifications - Part 3: Protection of persons against electric hazards	Published but in review stage to be revised
ISO/DIS 6469-3 Electrically propelled road vehicles - Safety specifications - Part 3: Protection of persons against electric shock	Enquiry stage but voting closed
ISO 8713:2005 Electric road vehicles - Vocabulary	Published
ISO/CD 8713 Electric road vehicles - Vocabulary	Committee stage, voting and comments stage closed
ISO 8714:2002 Electric road vehicles - Reference energy consumption and range - Test procedures for passenger cars and light commercial vehicles	Review stage closed
ISO 8715:2001 Electric road vehicles - Road operating characteristics	Review stage, International Standard confirmed
ISO/DIS 12405-1 Electrically propelled road vehicles - Test specification for lithium-Ion traction battery systems - Part 1: High power applications	Enquiry stage but voting closed
ISO/AWI 12405-2 Electrically propelled road vehicles - Test specification for lithium-Ion traction battery systems - Part 2: High energy applications	Preliminary stage, proposal for new project received
ISO/CD 15118-1 Road vehicles - Communication protocol between electric vehicle and grid - Part 1: Definitions and use-case	Committee stage, draft study/ballot initiated
ISO/NP 15118-2 Road vehicles - Communication protocol between electric vehicle and grid - Part 2: Sequence diagrams and communication layers	Proposal stage, new project approved
SO/AWI 23274-2 Hybrid-electric road vehicles - Exhaust emissions and fuel consumption measurements - Part 2: Externally chargeable vehicles	New project registered in the Technical Committee work program

TABLE IV. ISO STANDARDS

Table 5 provides details of some relevant International Electromechanical Commission (IEC) EV standards and their status.

Standard	Status
Electric vehicle conductive charging system - Part 1: General requirements (IEC 69/156/CD:2008)	Published
Secondary batteries for the propulsion of electric road vehicles - Part 4: Performance testing for lithium-ion cells (IEC 21/697/CD:2009)	Published
Secondary batteries for the propulsion of electric road vehicles - Part 5: Reliability and abuse testing for lithium-ion cells (IEC 21/698/CD:2009)	Published
Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles - Part 1: Charging of electric vehicles up to 250 A a.c. and 400 A d.c. (IEC 23H/222/CD:2010)	Published
Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles - Part 2: Dimensional interchangeability requirements for pin and contact-tube accessories (IEC 23H/223/CD:2010)	Published
IEC 60349-2 Ed.3: Electric traction - Rotating electrical machines for rail and road vehicles - Part 2: Electronic converter-fed alternating current motors	Published
IEC 61982-4 Ed.1: Secondary batteries for the propulsion of electric road vehicles - Part 4: Performance testing for lithium-ion cells	Published
IEC 62660-1 Ed. 1 (Re-numbered from IEC 61982-4): Secondary batteries for the propulsion of electric road vehicles - Part 1: Performance testing for lithium-ion cells	Published
IEC 62660-2 Ed 1 (Re-numbered from IEC 61982-5): Secondary batteries for the propulsion of electric road vehicles - Part 2: Reliability and abuse testing for lithium-ion cells	Published
MT 8, Maintenance of IEC 62196-1 Ed. 1.0 Plugs, Socket-Outlets, Vehicle Couplers and Vehicle inlets - Conductive Charging of Electric Vehicles - Part 1: Charging of electric vehicles up to 250 A a.c. and 400 A d.c.	Published
Future IEC 62196-3: Plugs, socket-outlets, and vehicle couplers - conductive charging of electric vehicles - Part 3: Dimensional interchangeability requirements for pin and contact-tube coupler with rated operating voltage up to 1 000 V d.c. and rated current up to 400 A for dedicated d.c. charging	In preparation
IEC 62196-2 Ed 1: Plugs, socket-outlets and vehicle couplers - Conductive charging of electric vehicles - Part 2: Dimensional interchangeability requirements for a.c. pin and contact-tube accessories	Revised and Published
IEC 62196-1, Ed 2: Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements	Published
IEC 69/75/CD, Electric power equipment for electric road vehicles	Published
IEC 61851-2-1, Ed.1: Electric vehicle conductive charging system - Part 2-1: Electric vehicles requirements for conductive connection to an AC/DC supply	Published
IEC 61851-2-2, Ed.1: Electric vehicle conductive charging system - Part 2-2: A.C. electric vehicles charging station	Published
IEC 61851-2-3 Ed.1.0: Electric vehicles conductive charging system - Part 2-3: D.C. Electric vehicle charging station	Published

TABLE V. IEC STANDARDS

Table 6 provides details of some relevant Japan Electric Vehicle Association Standards (JEVS) EV standards, which are all published.

Standard
C601:2000 Plugs and receptacles for EV charging
D001-1995 Dimensions and Construction of Valve Regulated Lead-Acid Batteries for EVs
D002:1999 Dimensions and Construction of sealed nickel-metal hydride batteries for EVs
D701-1994 Capacity test procedure of lead-acid batteries for EVs
D702-1994 Energy density test procedure of lead-acid batteries for EVs
D703-1994 Power density test procedure of lead-acid batteries for EVs
D704-1997 Cycle life test procedure of valve regulated lead-acid batteries for EVs
D705:1999 Capacity test procedure of sealed nickel-metal hydride batteries for EVs
D706:1999 Energy density test procedure of sealed nickel-metal hydride batteries for EVs
D707:1999 Specific power and peak power test procedure of sealed nickel-metal hydride batteries for EVs
D708:1999 Cycle life test procedure of sealed nickel-metal hydride batteries for EVs
D709:1999 Dynamic capacity test procedure of sealed nickel-metal hydride batteries for EVs
E701-1994 Combined power measurement of electric motors and controllers for EVs
E702-1994 Power measurement of electric motors equivalent to the on-board state for EVs
E901-85 Nameplates of electric motor and controller for EVs
G101-1993 Chargers applicable to quick charging system at Eco-Station
G102-1993 Lead-acid batteries applicable to quick charging system at Eco-Station for EVs
G103-1993 Charging stands applicable to quick charging system at Eco-Station for EVs
G104-1995 Communications Protocol Applicable to Quick Charging System at Eco-Station
G105-1993 Connectors applicable to quick charging system at Eco-Station for EVs
G106:2000 EV inductive charging system: General requirements
G107:2000 EV inductive charging system: Manual connection
G108:2001 EV inductive charging system: Software interface
G109:2001 EV inductive charging system: General requirements
G901-85 Nameplates of battery charger for EVs
Z101-87 General rules of running test method of EVs
Z102-87 Maximum speed test method of EVs
Z103-87 Range test method of EVs
Z104-87 Climbing hill test method of EVs
Z105-88 Energy economy test method of EVs
Z106-88 Energy consumption test method of EVs
Z107-88 Combined test method of electric motors and controllers for EVs
Z108-1994 Electric Vehicle - Measurement for driving range and energy consumption
Z109-1995 EV - Measurement for acceleration
Z110-1995 EV - Measurement for maximum cruising speed
Z111-1995 EV - Measurement for reference energy consumption
Z112-1996 EV - Measurement for climbing
Z804:1998 Symbols for controls, Indicators & telltales for EVs
Z805:1998 Glossary of terms relating to EVs (General of vehicles)
Z806:1998 Glossary of terms relating to EVs (Electric motors & controllers)
Z807:1998 Glossary of terms relating to EVs (Batteries)
Z808:1998 Glossary of terms relating to EVs (Chargers)
Z901-1995 Electric Vehicle - Standard Form of Specification (Form of Main Specification)

TABLE VI. JEVS STANDARDS

It is obvious from these tables that there are many participants, technical committees and groups internationally. Thus there is much duplication. This was referred to as a 'tsunami of codes and standards' by Steven Rosenstock of Edison Electric Institute at the IEEE P1809 Kickoff Meeting on EVs in February [13].

Pilot schemes are probably the most practical way to determine the technology solutions and standards that suits all market participants and more importantly the customer. This has been recognized in most countries with EV policies and targets. The EU, USA, UK, Ireland, Japan, Korea, China, Taiwan, Korea, Spain, France and Germany to name just a few have a variety of EV pilot projects underway [14].

IV. CHARGING INFRASTRUCTURE

It is important that there is a merging of standards and charging technology so that charging infrastructure is common, customers are comfortable with the technology and manufacturing costs are reduced. Already there exist different plugs, two charging terminology, 'level', which is used in the North America mostly and 'mode' used by the European based standards organizations. Interestingly, level is used widely in Europe. Earthing requirements also vary. Some EV manufacturers (i.e. Ford, General Motors, Volkswagen, Fiat, Toyota and Mitsubishi) agreed on a common, apparently 3-point (live, neutral and earth) plug standard for charging EVs in April 2009. In the EU there is the multiphase 'Mennekes' plug and the Électricité de France (EDF) single-phase or three-phase plugs, which involves Nissan and Renault. Figure 1 shows some of the plugs and sockets.

iMiev Socket

J1772 Plug & Socket

Mennekes Plug & Socket

Nissan Plug & Socket

Th!nk Plug

Volt Plug

Yazaki Plug

Ford Plug & Socket

Figure 1. Some EV Plugs & Sockets

Harmonization of certain aspects, particularly a universal socket and plug is vital, but this will not happen over night, rather through trial and error to ensure that the best system is achieved. It is suggested that ‘earthing’ and safety be under the remit of the electricity sector, as it is particular to each geographical areas practices and procedures. This needs attention soon. Billing and the customer graphical user interface on all public charging stations should be standard and user friendly, similar to an Automated Teller Machine (ATM) in the banking sector.

References [14 and 15] provide details of charging infrastructure in the USA and Canada. Such documents are very useful and valuable for local governments, those responsible for building regulation and permitting and property owners. It is recommended that a similar document be prepared for other regions as part of pilot schemes. Aspects which need to be examined and standardized include the following:

- Signage,
- Layouts, access and lighting in areas where public charging is proposed,
- Disabled persons requirements,
- Installations on properties subject to flooding,
- Certification of charging equipment,
- Trip hazards, liability issues and public insurance,
- Ventilation,
- LEED and BRE building certification requirements,
- Installation certification,
- Engineering design, construction and permitting on public and private property,
- Charging post ownership, maintenance and operation, metering and subscription services,
- Smart metering for home charging to control the time of charging, which can be related to costs, time of day and so forth,
- Battery swopping option,
- Vandal proofing,

In addition to charging stations an Israeli company called Better Place proposes a battery swopping drive-in station [16]. Internationally it is expected that there will be three levels of socket charging [17 - 19]. This will vary slightly from country to country depending on the voltage, frequency, transmission standards and plug standards in terms of the rating of the plug in amperes. An EV may have a higher internal electric capacity, but this will be limited by the grid connection [20]. Table 7 gives an indication of the power demand and charging options for Ireland based on the existing grid circuitry.

TABLE VII. CHARGING OPTIONS & POWER

Level	Type	Electrical	Resulting Charge	Time to Charge	Power
Level (Mode) 1	Standard (Domestic)	230V 16A 1 or 3 phase	100%	6 to 8 hours	3kW to 10kW
Level (Mode) 2	Opportunity	400V 32A	50%	30 minutes	22kW
Level (Mode) 2	Emergency	400V 32A	20km	10 minutes	22kW
Level (Mode) 3	Range Extension	400V 63A	80%	30 minutes	44kW

Figure 2 presents some of the numerous on-street and off-street charging posts.

Home, USA

On-Street, France

Private Garage, Italy

On-Street, Netherlands

Three-Pin Charging, UK

On-Street, Rotherdam

On-Street, London

On-Street, USA

Battery Swop

Fast On-Street, Japan

Figure 2. Some On-Street & Off-Street Charging Stations

V. SUMMARY & CONCLUSION

In summary the automobile industry and the electricity sector will undergo a series of evolutionary changes as the transport fleet is electrified. There are a number of economic and environmental benefits to the introduction of EVs, including employment in R&D, manufacturing and deployment, a reduction on fossil fuel dependency, an opportunity to better integrate renewable energy sources and ultimately ensure higher energy efficiency, better security of energy supply with an associated reduction in GHG emissions, localized air and noise pollution. This 'EVlotion', will make for a very interesting 10 years for the engineers involved.

However, it is obvious from the comprehensive table of existing and proposed standards that there are many participants, technical committees and groups internationally. Thus there is much duplication. Pilot schemes are probably the most practical way to determine the technology solutions and standards that suits all market participants and more importantly the customer. It is important that there is a merging of standards and charging technology so that charging infrastructure is common, customers are comfortable with the technology and manufacturing costs are reduced. It is suggested that 'earthing' and safety be under the remit of the electricity sector, as it is particular to each geographical areas practices and procedures. It is recommended that a charging infrastructure document be prepared as part of pilot schemes to establish best practice and share lessons learned. Items which need resolving and investigation include signage, ownership, construction, layout, management, maintenance and operation, certification, vandalism and liability and so forth. An international standard plug, socket and GUI type ATM portal for customer comfort is vital.

The next stage of this research is to compare and contrast the various standards and prepare a charging infrastructure document for Ireland. In conclusion this paper has established the state-of-the-art in EV charging infrastructure and provided a list of existing and proposed international standards, best practice and guidelines.

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