ONTARIO INTERNATIONAL AIRPORT FLEET ELECTRIFICATION BLUEPRINT

Zero-Emission Vehicle Technology Assessment for Energy Optimization

A Technological Overview

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Ontario Airport Fleet Electrification Task 4 Overview

Zero-Emission Vehicle (ZEV) Technology Assessment for Energy Optimization

- Explore innovative medium- and heavy-duty (MHD) charging and hydrogen refueling options to address potential infrastructure barriers.
- Assess appropriate vehicle-grid integration (VGI) stages.
- Include the ability to support emerging connectors or interfaces for heavy-duty vehicles, open-standards-based network communications.
- Elaborate on the VGI standards to predict charging behavior and associated impacts on the grid.
- Identify analytical tools, software applications, and data needed to improve future MHD ZEV infrastructure planning activities.
- Assess the potential for energy improvements from MHD ZEV infrastructure.

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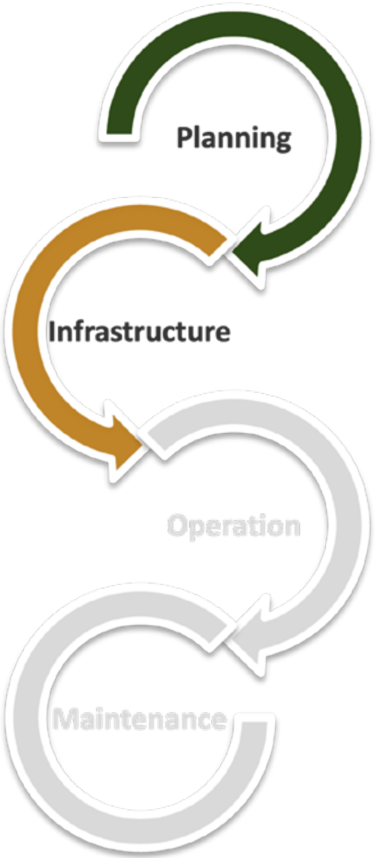
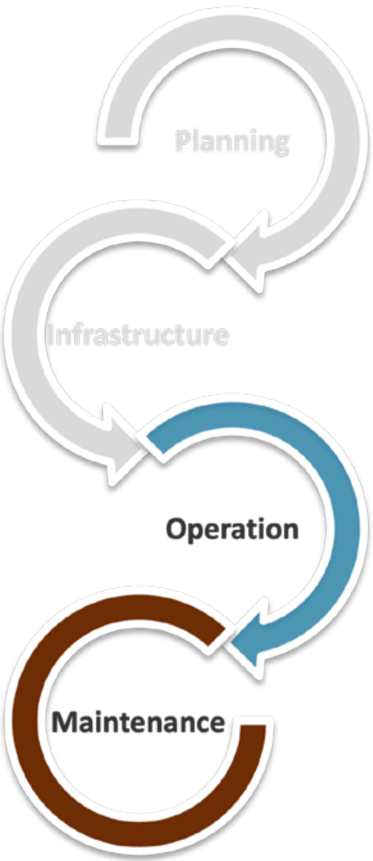
Planning → Infrastructure → Operation → Maintenance

Implementation Considerations and Best Practices



⇢ Develop individual vehicle specifications to meet operational requirements. Two basic strategies: • Identify best routes for a specific electric vehicle (EV) design. • Develop vehicle specifications to enable partial/full electrification of required routes. ⇢ Utilize *modeling and simulation tools to make informed choices.*	⇢ Select charging strategy for each route • Manual or automated plug-in • Static or dynamic inductive. ⇢ Engage stakeholders early in process • Utility provider • Airlines (ground support equipment [GSE] owner) • Local officials: government, emergency responders, code and permitting • General public.
⇢ Utility grid demand • Determine power needs for each vehicle in operation. • Work with utility to provide sufficient power. • May require added transformer or upgrades to local infrastructure. ⇢ Understand electricity rate structure for better planning • Utility base rates • Demand charges.	⇢ Placement of chargers understanding the space limitations ⇢ Logistics for moving vehicles through property will be affected by placement of chargers and need for access to chargers. ⇢ Scalability—plan initial infrastructure for potential scale-up • When installing initial charging stations, add capacity while trenching is open or install accessible conduits for future additions.

Implementation Considerations and Best Practices



⇢ Labor requirements for manual hookups to chargers and for maintaining charging equipment for plug-in options. ⇢ Optimize operations for charging requirements based on time to charge. ⇢ Training for operators and users • Train staff to be aware of the technology. • Driving style can have a significant effect on efficiency.	• Drivers can forget special operating procedures if they don't operate the EVs. • Plan for continual training based on driver turnover. ⇢Deploying additional EVs will impact operator training, maintenance training/equipment, and infrastructure. ⇢Maintaining operability during power outages—backup generators or battery-based resources may be necessary.
⇢ During warranty period, on-site vehicle manufacturer staff usually handle repairs and preventive maintenance. ⇢ Training for maintenance staff • Work with EV manufacturers to provide initial training. • Training for working on high-voltage electric systems.	• Consider need for follow-up training with changes in staff. ⇢ Should resort to special tools for troubleshooting and diagnosing issues with advanced systems. ⇢ Develop list of parts to keep in inventory to avoid long downtimes. ⇢ Collect data and perform analysis of better understanding of the system response and future expansions.

Overview of Topics Addressed

Vehicle Inventory

- Analysis of provided vehicles list and classification of the fleet based on vehicle roles.
- Detailed available EV alternative list for each kind of vehicle in airport fleet.

EVSE

- General overview of the electric vehicle supply equipment (EVSE) technology and MHD vehicle charging.
- Detail on different kinds of EVSE stations—the chargers.
- List of available EVSE for each category with discussions on connectors, advantages, and disadvantages.

Hydrogen Vehicle

- Overview of hydrogen-based vehicles and refueling process.
- Hydrogen refueling infrastructure and key concepts.
- Available hydrogen-based vehicles and refueling station cost dynamics.
- Status of hydrogen infrastructure in California.

Tools and Resources

- NREL tools for EV infrastructure design and optimization.
- Other tools and resources for EV and hydrogen.

Grid Impacts

- Analysis from Southern California Edison.
- Future EV allocations and recommendations.

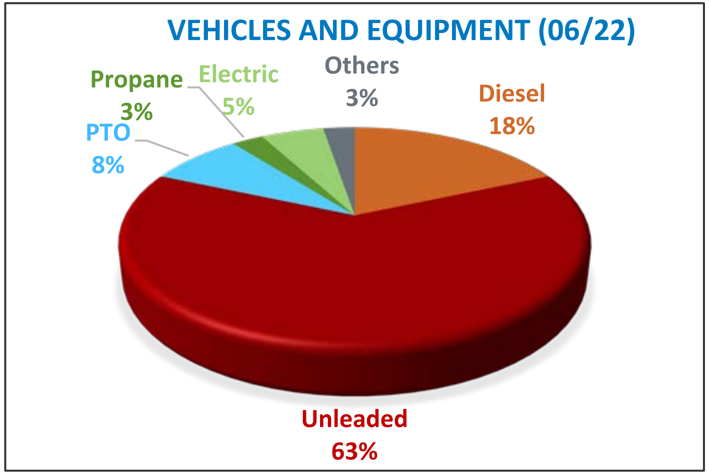
Overview of Ontario International Airport Authority Vehicle Inventory

JBT Facilities Vehicle List
JBT BHS & Boarding Bridge Vehicle List
ABM Custodial Vehicle List
Master Landscape Vehicle List
ONTTEC Vehicle List

Light Duty	27
Medium/Heavy Duty	17

Golf Cart	2
Scissor Lift	2
UTV	3

Police AOB Department	
Vehicle	**Number**
Ford Explorer	24
Chevrolet Tahoe	5
Chevrolet Colorado	2
Ford F150	1



Based on the inventory lists and the type of vehicles, following lists are proposed as alternative electric options

Electric Vehicles – Sedan & SUV

Model	Manufacturer	Range (miles)	Engine	
Bolt EV	Chevrolet	259	150-kW electric motor	SEDAN
MX-30	Mazda	100	81-kW electric motor	
Leaf (40-kWh battery pack)	Nissan	149	110-kW electric motor	
Leaf (62-kWh battery pack)	Nissan	226	160-kW electric motor	
Model 3 (Long-Range) AWD	Tesla	353	98-kW and 195-kW electric motors	
Model 3 Performance AWD	Tesla	315	131-kW and 190-kW electric motors	
Model 3 RWD	Tesla	272	192-kW electric motor	
Mustang Mach-E RWD Extended	Ford	300	216-kW electric motor	
Ioniq Electric	Hyundai	170	100-kW electric motor	
e-tron quattro	Audi	222	141-kW and 172-kW electric motors	SUV
Q4 e-tron quattro	Audi	241	80-kW and 150-kW electric motors	
Q4 e-tron Sportback quattro	Audi	241	80-kW and 150-kW electric motors	
RS e-tron GT	Audi	241	335-kW electric motor	
Mustang Mach-E AWD California	Ford	312	258-kW electric motors (x2)	

Note: This list is not comprehensive but provides an overview of the vehicle technology. The product availability and specs are likely to change over time.

Electric Vehicles – Vans and Pickups

Model	Manufacturer	Power	Range (miles)	Battery Size (kWh)
E-Transit Cargo Van	Ford	Ford 198-kW/266-hp motor	126	68
Transit 250/350 Cargo Van	Ford	-	-	-
Zevo 600	GM BrightDrop	GM BrightDrop Electric motor	250	-
EV Star Cargo	GreenPower Motor Company	Dana TM4 150 kW	150	118

VAN

Model	Manufacturer	Power	Range (miles)	Battery Size (kWh)	Type
F150 Lightning Platinum 4WD	Ford	210-kW electric motors (x2)	320	131	Pickup
E-450 Box/Work Truck/Cutaway	Ford	180 kW	120	129	Vocational/cab chassis
RT1	RIVIAN	835 hp	314	135	Pickup
EV Pickup	Hummer	1,000 hp	329	212.7	Pickup

**Ford E-450/F150 can also be used as ambulances and other utility applications.*

PICKUP

Note: This list is not comprehensive but provides an overview of the vehicle technology. The product availability and specs are likely to change over time.

Electric Vehicles – Utility Trucks (Medium and Heavy Duty)

Model	Manufacturer	Type	Engine	Battery (kWh)	Range (Miles)
220EV - Class 6	Peterbilt	Vocational/cab chassis	Dana TM4 SUMO MD HV2600 250 kW	141	100
220EV - Class 7	Peterbilt	Vocational/cab chassis	Dana TM4 SUMO MD HV3500 350 kW	141	100
520EV - Class 8	Peterbilt	Refuse	Meritor 14Xe e-axles	400	80–100
579EV - Class 8	Peterbilt	Tractor	Meritor 14Xe e-axles	400	150
LION6	Lion Electric	Vocational/cab chassis	Dana TM4 SUMO MD 250 kW (335 hp)	252	200
LION8 - Class 8	Lion Electric	Vocational/cab chassis	Dana TM4 SUMO HD 800 VDC 9-Phase 350 kW (470 hp)	252	170
LION8 Refuse ASL and REL - Class 8	Lion Electric	Refuse	Dana TM4 SUMO HD 800 VDC 9-Phase 350 kW (470 hp)	336	170
LION8T - Class 8	Lion Electric	Tractor	Meritor 2-Speed e-axle	653	260
LR	Mack	Refuse		376	
K270/K370	Kenworth	Vocational/cab chassis	Kenworth HV2600|Kenworth HV3500	282	200
T680E	Kenworth	Tractor	Meritor 14Xe e-axles	396	150
MT-50e	Freightliner Custom Chassis	Vocational/cab chassis	Proterra Electric Drive System|Dana eS9000r eAxle	226	170

TRUCKS

Note: This list is not comprehensive but provides an overview of the vehicle technology. The product availability and specs are likely to change over time.

Electric Vehicles – Shuttle Buses

Model	Manufacturer	Passenger Capacity	Battery (kWh)	Range (miles)	Charge Rate (kW)
Mobility G Series	Alpha	25	108/144	100–125	-
B Series Motors	Endera	16	151	135	180
EV Star+	Green Power	19	188	150	50
E-450	Lightning eMotors	24	86/129	80–120	80
E-550	Lightning eMotors	-	128	110	80
eLionM – 26’	Lion Electric	31	160	150	80
Micro Bird D-Series E-450	Blue Bird	28	88	100	13
EV S1LF	Optimal	-	113	125	60
Zeus 400 – 22’	Phoenix	18	63–156	70–160	50

Note: This list is not comprehensive but provides an overview of the vehicle technology. The product availability and specs are likely to change over time.

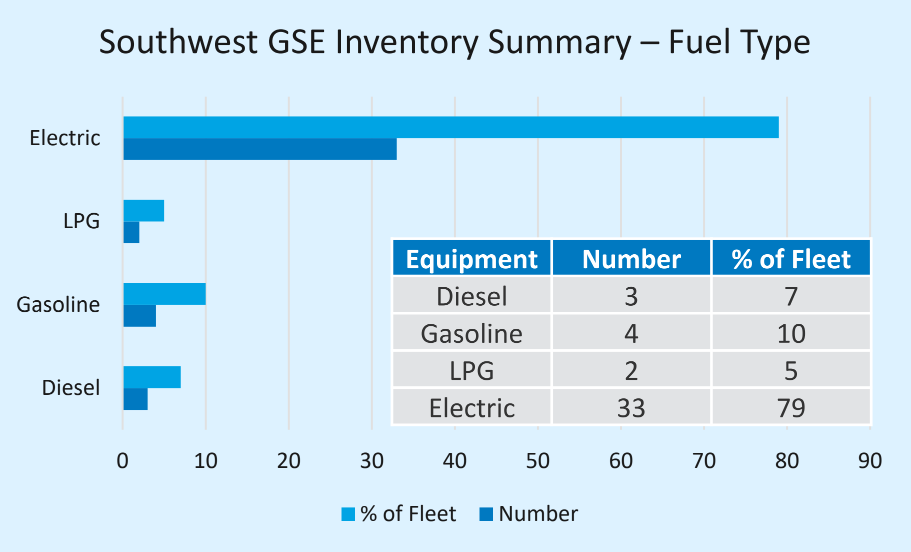
Electric Vehicles – Transit Buses

Model	Manufacturer	Passenger Capacity	Battery (kWh)	Range (miles)	Charge Rate (kW)
K9MD – 40’	BYD		266–446	203	150
BYD K11M – 60’	BYD	48–56	352–578	198	150
K7M – 30’	BYD	22	180	137	80
K7MER – 30’	BYD	21	226–313	196	150
Low Floor Plus – 30-40’	Gillig	35	296–444	-	-
EV250 – 30-32’	Green Power	25	210	175	100
EV350 – 40’	Green Power	40	350	185	200
eMotors City	Lightning eMotors	20–30	320	140–200	50
XE35 – 35’	New Flyer	67	350–454	179–220	150 depot/450 on route
XE40 – 40’	New Flyer	80	350–545	174–260	150 depot/450 on route
XE60 – 60’	New Flyer	123	525	153	150 depot/450 on route
LFSe+ – 40’	NovaBus	68/71	564	211–292	150 depot/450 on route
Catalyst XR – 35’ and 40’	Proterra	29/40	225	91–125	133 plug-in/177 overhead
Catalyst E2 – 35’ and 40’	Proterra	29/40	440	154–240	135 plug-in/355 overhead
Catalyst E2 – 40’	Proterra	40	440	163–232	132 plug-in/330 overhead
Catalyst E2 max – 40’	Proterra	40	660	221–329	132 plug-in/330 overhead
Catalyst ZX5+ – 40’	Proterra	40	675	205–329	135 plug-in/407 overhead

Note: This list is not comprehensive but provides an overview of the vehicle technology. The product availability and specs are likely to change over time.

Electric Vehicles – Ground Support Equipment

Graphic from iStock 1300694738



Equipment	Number	% of Fleet
Diesel	3	7
Gasoline	4	10
LPG	2	5
Electric	33	79

From the given data of Southwest GSE vehicle inventory, it is evident that the majority of vehicles are electrified. For reference to other GSE owners, the following list of available electric alternatives is provided

Electric Vehicles – Ground Support Equipment

Make	Model	Reference	
Eagle	ETT-16 Aircraft Tug	https://eagletugs.com/aircraft-tugs/electric/eagle-tt-electric-aircraft-tugs-ett-16	eGSE
Eagle	ETT-12 Aircraft Tug	https://eagletugs.com/aircraft-tugs/electric/eagle-tt-electric-aircraft-tugs-ett-12	eGSE
Aero Specialties	Jet-16 baggage/cargo tow tractor	https://www.aerospecialties.com/aviation-ground-support-equipment-gse-products/tow-tugs-pushback-tractors/small-0-7500-dbp/tld-jet-16/	eGSE
Aero Specialties	Belt Loader	https://www.aerospecialties.com/aviation-ground-support-equipment-gse-products/aviation-baggage-cargo-service-equipment/belt-loaders/charlatte-cbl150e-electric-belt-loader/	eGSE
JBT	Lektro Tow & Pushback	https://www.jbtc.com/aerotech/products-and-services/ground-support-equipment/electric-gse/lektro-electric-towbarless-tractors/	eGSE
JBT	Ranger 15E Cargo Loader	https://www.jbtc.com/aerotech/products-and-services/ground-support-equipment/cargo-loaders/ranger-15e-electric-cargo-loader/	eGSE
JBT	Commander 15i E Cargo Loader	https://www.jbtc.com/aerotech/products-and-services/ground-support-equipment/cargo-loaders/commander-15i-e-electric-cargo-loader/	eGSE
JBT	Commander 30i E Cargo Loader	https://www.jbtc.com/aerotech/products-and-services/ground-support-equipment/cargo-loaders/commander-30i-e-electric-cargo-loader/	eGSE
JBT	CPT-7 Cargo Transporter	https://www.jbtc.com/aerotech/products-and-services/ground-support-equipment/cargo-loaders/cpt-7/	eGSE
JBT	AmpTek Load Sharing	https://www.jbtc.com/aerotech/products-and-services/ground-support-equipment/amptek-load-sharing/	eGSE
JBT	Passenger Steps	https://www.jbtc.com/aerotech/products-and-services/ground-support-equipment/electric-gse/electric-passenger-steps/	eGSE
Mercury	Lavatory truck	https://mercurygse.com/ground-support-equipment/tld-lsp-900-v-e-electric-lavatory-truck/	eGSE
John Deere	Gator	https://www.deere.com/en/gator-utility-vehicles/traditional-gators/te-4x2-electric-utility-vehicle/	eGSE
Global Environmental Products	M4	https://globalsweeper.com/electric-street-sweepers	SWEEPER
Duvelo	D.Zero Plus	https://www.dulevo.com/us/products/street-sweepers/dulevo-d-zero2/	SWEEPER

EVSE – Overview

AC Charging or AC EVSE

- Pass power from the utility to the vehicle with the use of an onboard power electronics converter.
- Typically limited to 20 kW.
- Larger power not accommodated due to space constraints for the larger electronic converter requirement.
- Some exceptions for vehicles with available space to accommodate high-power converters.

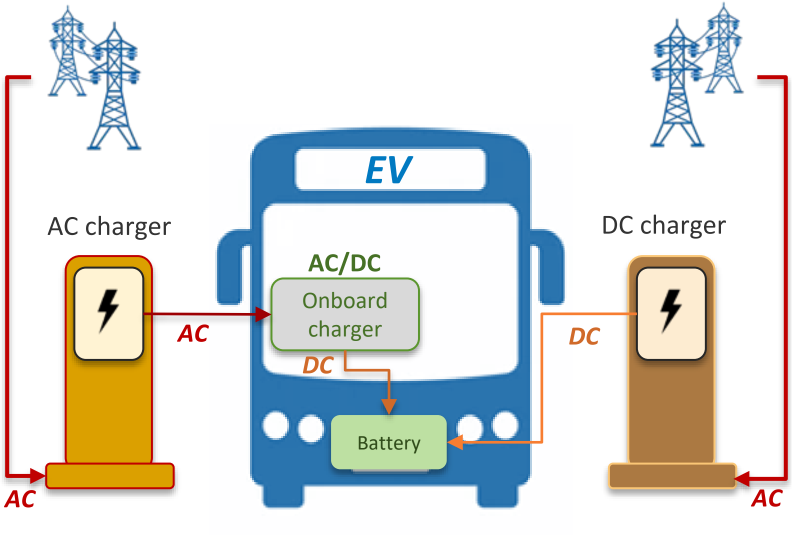


Illustration by Shafquat Khan, NREL

DC Charging or DC EVSE

- Grid power conversion to DC is arranged outside the vehicle.
- Direct current fast charger (DCFC) provides DC power directly to the battery of the vehicle.
- Power conversion provides added modularity for having no space constraints.
- State of the art supports power transfer of 350 kW in plug-in type.

ZEV Dispenser Statistics

State	Biodiesel	CNG	E85	Electric			Hydrogen		LNG	Propane		Total
				Level 1	Level 2	DC Fast	Retail	Non-Retail		Primary	Secondary	
California	21	164	282	171	28,181	7,608	53	0	15	133	79	36,736

https://afdc.energy.gov/stations/states

EVSE – Cost Overview

<u>**Primary Cost Drivers for EVSE**</u>

- **Power level of unit (kW)**
  - Level 2 EVSE tends to be the cheapest, which varies from $500–$7,000 USD, whereas DCFC cost varies from $10,000–$30,000 USD.
- **Number of charging ports per unit**
  - Chargers with multiple connectors/charging ports tend to be cheaper ($/port) with higher modularity in terms of use.
  - Software can enable simultaneous or sequential vehicle charging.
  - Pantograph and wireless pads can charge one vehicle at a time.
- **Dispenser type**
  - Wall-mounted units tend to be cheaper than pedestal-mounted, for hardware and installation.
  - Overhead pantographs are the most expensive infrastructure setup.
- **EVSE location and number of units installed**
  - Will have a large impact on construction and installation costs.
- **EVSE costs are variable and can be challenging to predict**
  - It is recommended to purchase and install only the minimum charging level and capabilities needed.

Note: The product price spectrum might change from what is listed here.

Charging Type	Power Level	Networkability	Price Range ($)
Level 1 AC	<2 kW	No	$500–$1,000
Level 2 AC	<8 kW	No	$500–$1,000
Level 2 AC	10–20 kW	No	$700–$1,500
Level 2 AC	<8 kW	Yes	$500–$1,000
Level 2 AC	10–20 kW	Yes	$3,000–$6,500
Level 3 DCFC	20–30 kW	Yes	$10,000–$40,000
Level 3 DCFC	50–150 kW	Yes	$50,000–$100,000
Level 3 DCFC	>150 kW	Yes	$150,000+

Common DCFC Power Rating for Auxiliary Circuit Selection		
Minimum Braker Rating (A)	Maximum Continuous Current	Power Rating (kW)
40	30	25
75	60	50
150	120	100
225	180	150
300	240	200
530	420	350

https://www.gladstein.org/research/electric-vehicle-charging-guidebook-for-medium-and-heavy-duty-commercial-fleets/

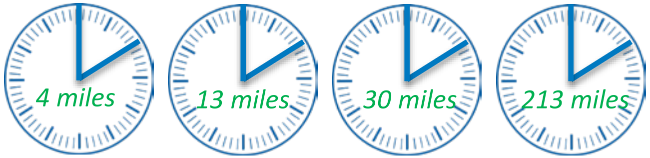
EVSE – Overview of Charging MHD Vehicles

Transit bus, refuse truck, delivery van, shuttle bus, yard hostler, utility, and work truck.

Gross Vehicle Weight Rating (lbs)	Federal Highway Administration		US Census Bureau
	Vehicle Class	GVWR Catagory	VIUS Classes
<6,000	Class 1: <6,000 lbs	Light Duty <10,000 lbs	Light Duty <10,000 lbs
10,000	Class 2: 6,001–10,000lbs		
14,000	Class 3: 10,001–14,000 lbs	Medium Duty 10,001–26,000 lbs	Medium Duty 10,001–19,500 lbs
16,000	Class 4: 14,001–16,000 lbs		
19,500	Class 5: 16,001–19,500 lbs		
26,000	Class 6: 19,501–26,000 lbs		Light Heavy Duty: 19,001–26,000 lbs
33,000	Class 7: 26,001–33,000 lbs	Heavy Duty >26,001 lbs	Heavy Duty >26,001 lbs
>33,000	Class 8: >33,001 lbs		

- Bigger battery sizes require longer time to charge, which in many cases might not be practical.
- High-power charging is a plausible solution, but megawatt-level charging is required to match the performance of gas refueling.
- Lack of consensus on standards for megawatt-level charging is a prevailing challenge.

Range (miles) added for 10 min of charge



7.7 kW | 22 kW | 50 kW | 350 kW

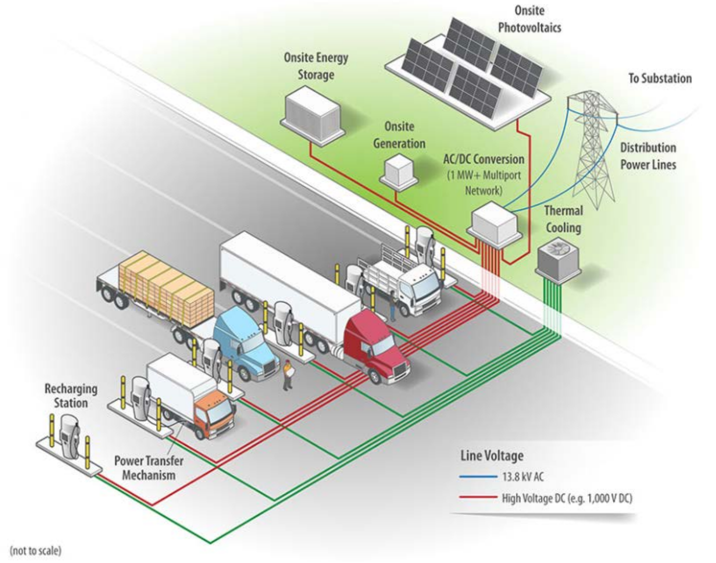
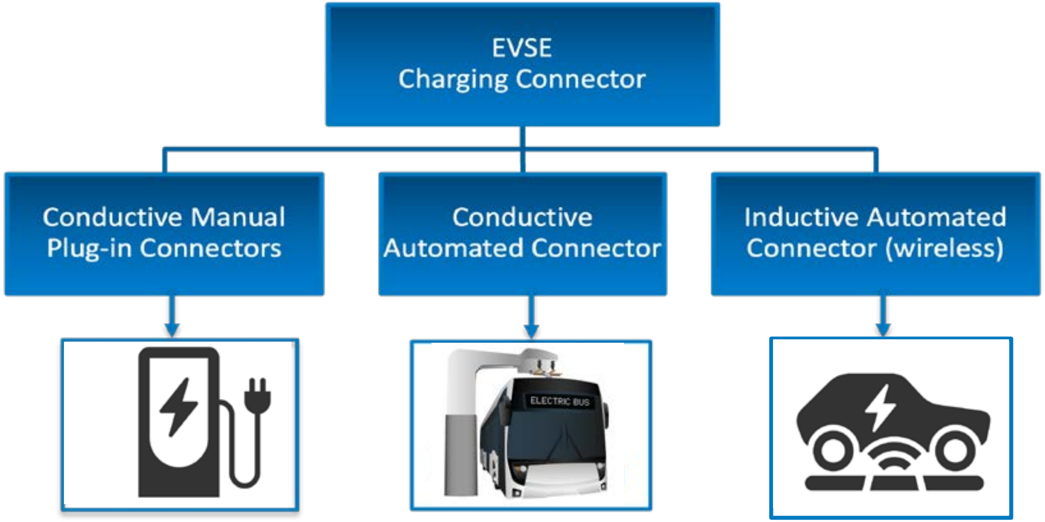


Illustration by Al Hicks, NREL

- Challenges prevail from the grid side to accommodate the power requirement and variable peak demand for MHD charging.
- *CharIN and NREL are developing a universal Megawatt Charging System with charging capacity of up to 3.75 MW. Such high-power charging would reduce the charging time and make a viable business case.*

Types of EVSE



Illustrations from iStock, 1012445134 and 1055421260

Power Level	Up to 350 kW	Typically up to 500 kW	Up to 250 kW
R&D	500 kW	-	500 kW
Voltage Type	AC/DC and AC + DC	DC	AC
Operation	Manual	Automatic	Automatic

Conductive Manual Plug-In Connectors

EVSE Equipment Configurations for DC Fast Chargers

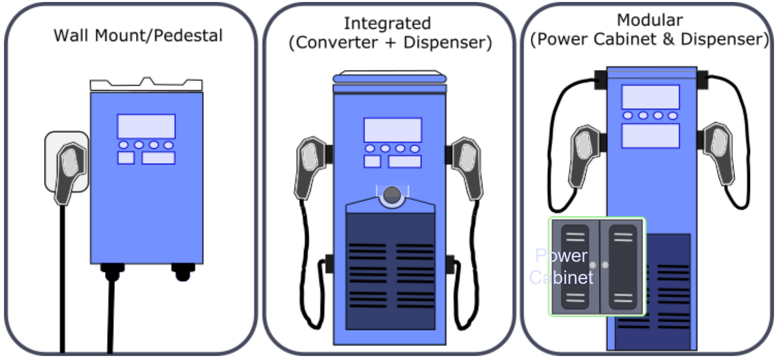
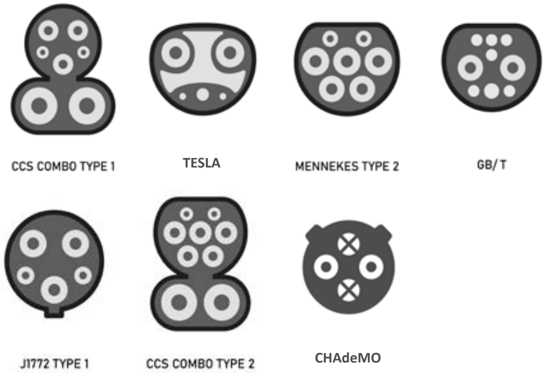


Illustration by Shafquat Khan, NREL

EVSE Standard Connectors



Illustrations from iStock, 1419427424 and 1307678967

Advantages:

- Proven solution with high number of options in the market
- Lower capital cost per charge port
- Subsurface work generally limited to channel cables for power cabinets.

Disadvantages:

- Requires an individual to connect the vehicle before charging
- Additional task with cable management and electrical safety
- Logistic issues regarding several scopes to human error.

Comparison Of Connectors for High-Power Charging

	GB/T	New GB/T	CHAdeMO	CCS1	CCS2	Tesla
Max Power (kW)	237.5	900	400	500	500	250
Range (miles) add/minute charge	1.5	5.8	2.6	3.2	3.2	1.6
Communication protocol	CAN	CAN	CAN	PLC	PLC	CAN
Communication standard	SAE J1939	SAE J1939	ISO 11898	ISO 15118	ISO 15118	SAE J2411
Related standard	IEC 61851	IEC 61851	IEC 61851 , IEEE 2030.1	IEC 61851, SAE J1772	-	-
Geography	China, India	China	Global	U.S.	EU, South Korea, Australia	Global

Level 2 EVSE Manufacturer Overview

Name		Current Output	Output Power	Power Connection	Weight	Charging Cable Length	Supported Communication Interfaces	Installation Type	Price
ClipperCreek	LCS	8–24 A	Up to 5.8 kW	Plug-in: NEMA 6-50, 14-30/14-50 or hardwired	5.2 lb/6.4 lb	25 ft	-	Wall/pedestal	$379–$515
	HCS	16–64 A	Up to 15.4 kW	Plug-in: NEMA 6-50, 14-50 or hardwired	13.5 lb/14 lb	25 ft	-	Wall/pedestal	$565–$969
	CS	Up to 80 A	Up to 19.2 kW	Hardwired	36 lb/47 lb	25 ft	-	Wall/pedestal	$1,750–$3,095
ChargePoint	HomeFlex	16–50 A	Up to 12 kW	Plug-in: NEMA 6-50, 14-50 or hardwired		23 ft	ChargePoint app, software upgrades over WiFi	Wall	-
	CT4000 Family	16–30 A	Up to 7.2 kW	Hardwired		18 ft/23 ft	2.4-GHz WiFi (802.11 b/g/n), 4G LTE	Wall/pedestal	-
	CPF50	16–50 A	Up to 12 kW	Hardwired		18 ft/23 ft	2.4/5 GHz WiFi (802.11 b/g/n), 4G LTE	Wall/pedestal	-
SolarEdge	SolarEdge Smart EV Inverter	16–40 A	Up to 9.6 kW	Plug-in: NEMA 6-50, 14-50 or hardwired	6.3 lb	25 ft	WiFi (built-in antenna included), Ethernet, RS485, and cellular (optional)	Wall	-
	EV Charging Single Phase Inverter	Up to 40 A	Up to 9.6 kW	Hardwired	22–26.2 lb	25 ft	RS485, Ethernet, ZigBee (optional), cellular (optional)	Wall	-

Note: This list is not comprehensive but provides an overview for the technology. The product spectrum might change from what is listed here.

Level 2 EVSE Manufacturer Overview (Contd.)

Name		Current Output	Output Power	Power Connection	Weight	Charging Cable Length	Supported Communication interfaces	Warranty	Installation Type	Price
Electrify America	Homestation - Level 2 home charger	16–40 A	Up to 9.6 kW	Plug-in: NEMA, 14-50 or hardwired	19.8 lb (approx.)	24 ft	Wi-Fi	3 years	Wall	$649
Wall Box	Pulsar Plus (40 A)	6–40 A	Up to 9.6 kW	Plug-in: NEMA, 14-50 or hardwired	4.4 lb	25 ft	Wi-Fi, Bluetooth	3 years	Wall	$649
	Pulsar Plus (48 A)	6–48 A	Up to 11.5 kW	Hardwired	4.4 lb	25 ft	Wi-Fi, Bluetooth	3 years	Wall	$699
Evo Charge	EVOCHARGE EVSE	Up to 32 A	Up to 7.7 kW	Plug-in: NEMA 6-50 or hardwired	14 lb/15 lb	18 ft/25 ft	Non-networked	-	Wall/pedestal	$499
	EVOCHARGE IEVSE	Up to 32 A	Up to 7.7 kW	Plug-in: NEMA 6-50 or hardwired	14 lb/15 lb	18 ft/25 ft	Wi-Fi enabled, OCPP Compliant	-	Wall/pedestal	$899
	EVOCHARGE IEVSE Plus	Up to 32 A	Up to 7.7 kW	Hardwired	14 lb/15 lb	18 ft/25 ft	OCPP, RFID, 4G-LTE, Wi-Fi	3 years	Wall/pedestal	$1,399
ENEL X	JuiceBox Pro 32/40/48 (residential)	32–48 A	Up to 11.5 kW	Plug-in: NEMA 6-50 (40 A), NEMA 14-50, or hardwired 48 A; hardwired	15 lb/17 lb (hardwired 48 A)	25 ft	Wi-Fi	3 years	Wall mount/ stand	$619–$689
	JuiceBox Pro 32/40/48 (commercial)	32–48 A	Up to 11.5 kW	Plug-in: NEMA 6-50 (40 A), NEMA 14-50, or hardwired 48 A; hardwired	15 lb/17 lb (hardwired 48 A)	25 ft	Wi-Fi integrated cellular (LTE), JuiceRouter, RFID/QR Code	3 years	Wall mount/ stand/pedestal	$1,349–$1,868

Note: This list is not comprehensive but provides an overview for the technology. The product spectrum might change from what is listed here.

High-Power EVSE Manufacturer Overview

Company	Model	Power (kW)	Voltage (VDC)	Ports	Connectors	Payment Comm.	Country	Standards: IEC	Standards: ISO	Standards: SAE
ABB	Terra HP	Up to 350	150–920	2	CCS1, CHAdeMO	OCPP	Switzerland	IEC61851-23	-	-
Siemens	VersiCharge Ultra	175	200–920	1 or 2	CCS1, CHAdeMO	OCPP 1.5/1.6	Germany	ISO/IEC15693, ISO/IEC18000-3, ISO/IEC14443A/B		-
EATON	Green Motion	50–150	200–1,000	1 or 2	CCS1, CHAdeMO	OCPP 1.6/2.0	U.S.-Ireland	IEC 61851-1	-	-
Beny Electrics	BDC-S	40–240	50–1,000	1	CCS2	OCPP 1.6	China	IEC/EN 61851, IEC/EN 62196	ISO-15118	-
BorgWarner	Iperion-120	60–120	75–950	2	CCS CHAdeMO	OCPP 2.0	U.S.	IEC 14443A ISO/IEC 14443A/B ISO/IEC 18092		-
Electrify America	Ultra fast, hyperfast	150–350	Up to 800	2	CCS, CHADeMO J1772	OCPP 1.6	U.S.	IEC 61851-1:2017	ISO 15118	-
Noodoe	DC(X)P	30–360	150–720	2	CCS1, CHAdeMO	OCPP 1.6 J	U.S.	ISO/IEC 14443 A/B	ISO 15118	-

Note: This list is not comprehensive but provides an overview for the technology. The product spectrum might change from what is listed here.

High-Power EVSE Manufacturer Overview (Contd.)

Company	Model	Power (kW)	Voltage (VDC)	Ports	Connectors	Payment Comm.	Country	Standard IEC	Standard ISO	Standard SAE
EV Box	Ultroniq	Up to 350	50–950	1 or 2	CCS, CHAdeMO	OCPP 1.5/2.0	Netherlands	-	ISO 14443, ISO 18092, ISO 15693, ISO 18000-3, Calypso	-
ChargePoint	Power Link	200–350	200–1,000	2	CCS1&2, CHAdeMO	OCPP	U.S.	-	-	-
BTC	ModularHPC	100–350	500–950	2	CHAdeMO & J1772 Combo	OCPP 1.5/1.6	U.S.	-	ISO 15118	SAE J1772
					CCS1			-	-	-
Efacec	HV350G2	Up to 350	Up to 920	2	CCS, CHAdeMO	-	Portugal	-	-	-
Tritium	PK 350	Up to 350	Up to 920	1 or 2	CCS, CHAdeMO	OCPP 1.6	Australia	IEC14443A ISO/IEC14443A/B, ISO/IEC15693, ISO/IEC18000-3		-
Rhombus Energy Solution	RES-D3-CS20-V2G	Up to 125	530–920	1	CCS 1	OCPP 1.6	U.S.	-	ISO 15118-22	SAE J1772
Freewire	Boost Charger	150	200 to 950	2	CCS1/CCS2, CHAdeMO	OCPP	U.S.		ISO 15693, ISO 14443	
InCharge	ICE-(60/120/180)	60–180	150–1,000	2	CCS1, CHAdeMO	OCPP 1.6J	U.S.	-	ISO14443 Type A & S50	-

Note: This list is not comprehensive but provides an overview for the technology. The product spectrum might change from what is listed here.

Conductive Automated Connector

Advantages of Pantograph Charger

- Does not require manual connection
- Fewer risks of tripping, other cord hazards
- No maintenance cost associated with faulty charger chord or chord management
- Scalable for charging along routes
- Higher power range and thus lower charge times.

Disadvantages of Pantograph Charger

- Heavy infrastructure, and thus larger footprint
- Higher cost of ownership
- Singular port for dedicated power towers.

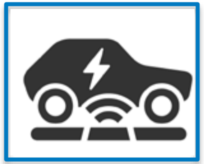
Pantograph Standards

- J3105-1: Infrastructure-Mounted Cross Rail Connection
- J3105-2: Vehicle-Mounted Pantograph Connection
- J3105-3: Enclosed Pin and Socket Connection.

Company	Model	Power (kW)	Voltage (VDC)	Current (A)	Connector Standards	Payment Comm.	Availability
ABB	HVC (150–450) PD	150–450	150–850	250–600	SAE J3105-1 SAE J3105-1 IEC 61851-23-1 ISO 15118	OCPP 1.6	U.S.
Heliox	Ultra-Fast 450	450	460–800	600–900	SAE J3105-1	OCPP 1.6J OCPP 2.0.1	U.S.
SCHUNK	• Depot • Inverted roof • Mounted underbody	Current rating of up to 1,000 A					U.S. (Wisconsin)
Wabtec	Different pantographs and charging reels						Germany

Note: This list is not comprehensive but provides an overview for the technology. The product spectrum might change from what is listed here.

Inductive Automated Connector (Wireless)



Advantages of Wireless Charging

- No physical connectors required
- Connector type does not play a role in station selection
- Connector cable faults do not affect charging session
- Higher personal safety with no requirement of cable handling
- No long-term cable wear and tear.

Challenges of Wireless Charging

- Not a mature market
- Higher capital cost associated
- Not many companies with comparable offerings
- New technology with undiscovered long-term challenges
- Extensive subsurface work required
- Misalignment might affect charging sessions.

Company	Country	Founded	Power (up to)	Efficiency (%)
Witricity	U.S.	2007	450 kW	90–93
Wave INC	U.S.	2011	250 kW	>90
Momentum	U.S.	2009	300 kW	>90
Hevo	U.S.	2011	8 kW	-
Mojo Mobility	U.S.	2005	20 kW	-
Electreon	Israel	2013	-	-
Elix	Canada	2013	8 kW	-

List of Primary Wireless EV Charging Standards

Standard Number	Drafting Institution
61980–1	IEC
61980–2	IEC
61980–3	IEC
19363	ISO
Subject 2750	UL
J2954	SAE
J1773	SAE
G106,G107	JEVs
G108,G109	JEVs
SZDB/Z 150	MSAM

Note: This list is not comprehensive but provides an overview for the technology. The product spectrum might change from what is listed here.

EVSE – Key Takeaways

Key Takeaways:

- *Selection of the correct EVSE depends on an in-depth analysis of the usage characteristics of the EVs.*
- *Correct EVSE is not only a selected brand, but also the part of an architecture that provides expansion without locking into a particular vendor. That involves number of ports, port capacity, and possible communication architecture that allow for demand-side management.*
- *Selected station architecture should provide enough space and capacity for future expansion.*
- *It is highly encouraged to use simulation-based analysis to identify optimal selection of port number, power level, and type.*
- *Data collection is of high priority for long-term EV charging station monitoring and data sharing.*

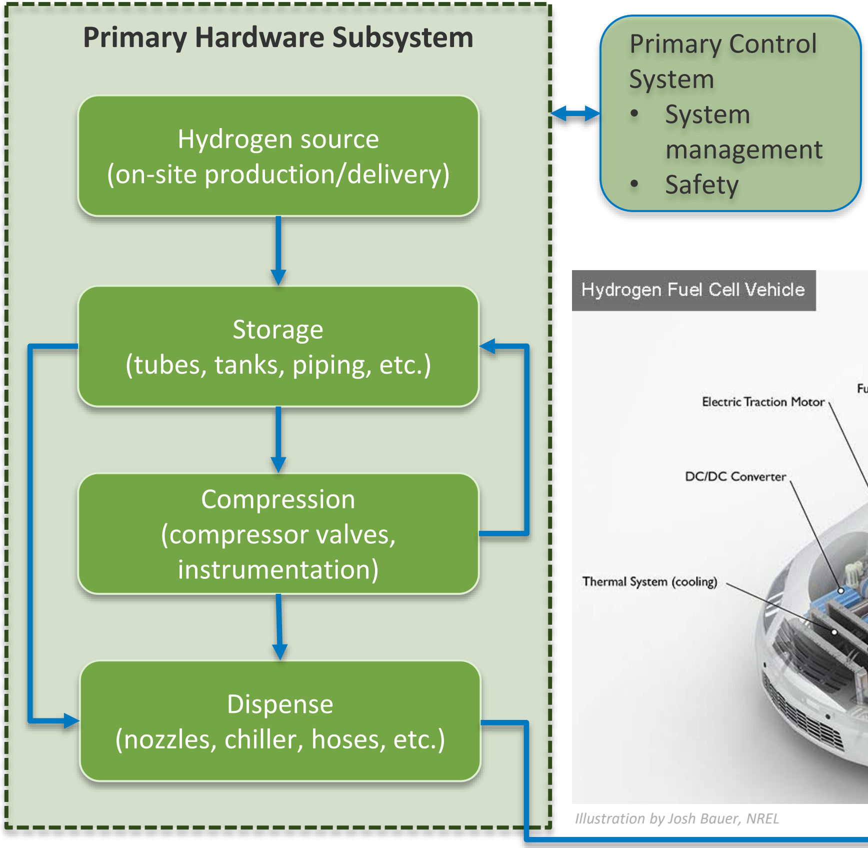
Grid-Side – Key Takeaways

<u>Key Takeaways:</u>

Analyzing the power allocation in each feeder coming into Ontario International Airport from the ***Southern California Edison Distribution Resources Plan External Portal*** *(https://drpep.sce.com/drpep/#):*

- *Analyzing from the provided link, reserve load circuit capacity and reserve substation load capability must be taken into consideration.*
- *The load allocation for EV-based load is highest for feeders Dalmatian and Hydrant and lowest for Nozzle.*
- *Thus, the dropdowns for EVSE will be more from the Dalmatian and Hydrant feeders.*
- *In-depth load assessment will be performed to predict any additional load requirement on each feeder and liaise with utility for surplus allocation.*
- *Feeders are also projected to incorporate distributed energy resources from residential and nonresidential photovoltaics, energy storage, etc. Impact of airport ground fleet electrification and growing distributed energy resources requires in-depth system analysis to assess long-term grid stability. The website provides hourly data that can be used for the analysis.*

General Hydrogen Station Subsystem



Pros:
- Quieter in drive
- High energy efficiency
- Produces no emissions (H_2O)
- Equivalent range to gasoline cars
- Similar performance to gasoline cars
- Incentivized by government.

Cons:
- More expensive than gasoline counterparts
- Low energy content volume (i.e., storage challenges)
- Refueling network is expensive to install
- Scarcity of stations.

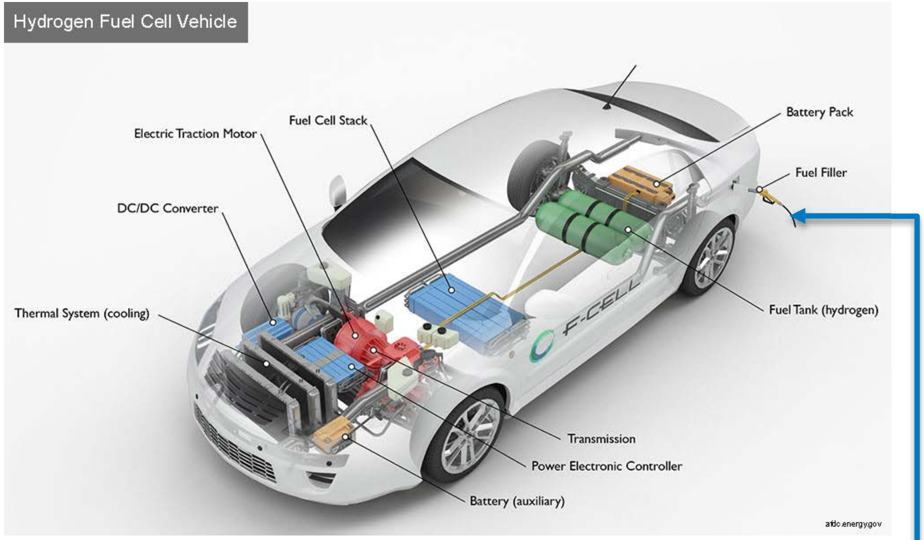
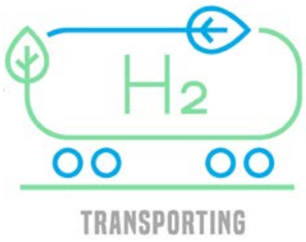


Illustration by Josh Bauer, NREL

Hydrogen Refueling Station

Refueling infrastructure varies based on different levels of hydrogen demand.

Delivered to site
- Delivered in liquefied form
- Delivered as gaseous hydrogen
- Delivered by tube trailer or via a pipeline.



On-site production and supply
- Electrolysis of water
- Small-scale reformation of natural gas.

Hydrogen refueller
- Cascade storage fill system
- Booster compressor fill system.

Hydrogen storage
- Stored in liquid form (−253°C)
- Stored as a compressed gas.

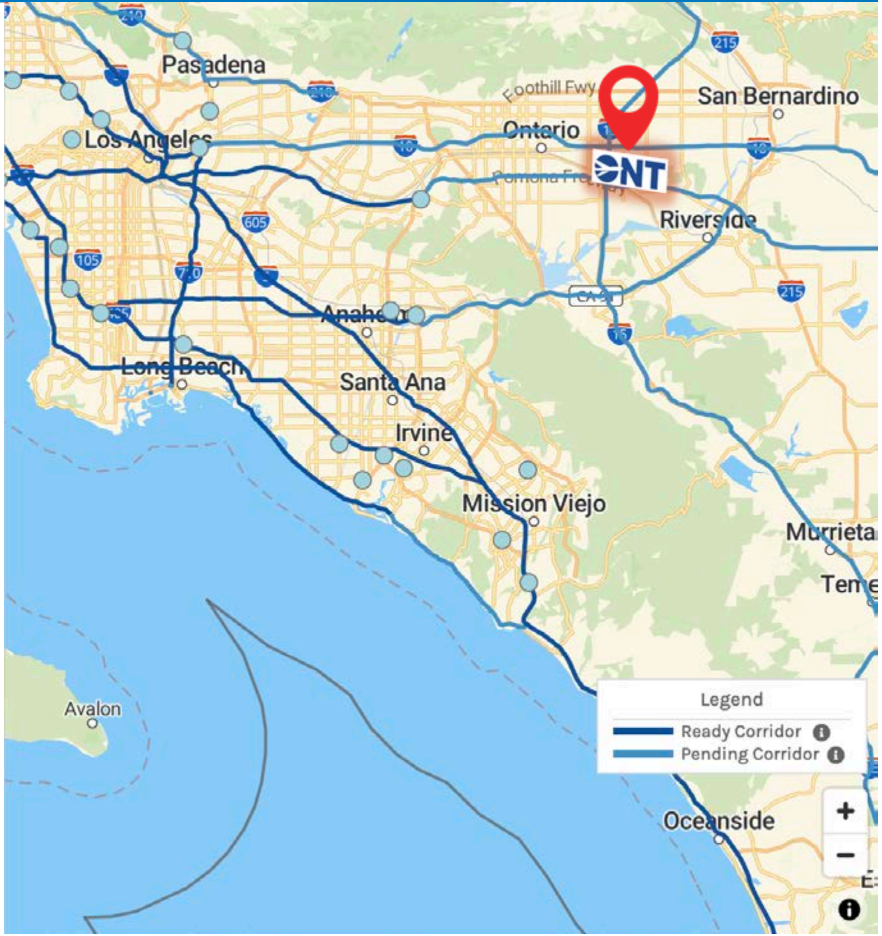
Illustrations from iStock, 1396863635 and 1340431385

Fuel Cell and Hydrogen Technology – California

- California has ready corridors and several pending corridors.
- Currently, most refueling stations are concentrated in **San Francisco, Los Angeles,** and **Sacramento.**
- Ontario International Airport comes within the vicinity of a pending corridor.

California Air Resources Board (CARB) Incentives	
Vehicle	Grant Amount
Fuel cell transit bus	$400,000

CARB also provides $4,500 rebates for fuel cell electric vehicles.



Fuel Cell Vehicles

Fuel Cell Vehicle Standards	
Location	Standard
U.S.	SAE J2601
Europe	ISO 19880-1
Japan	JPEC-S 0003

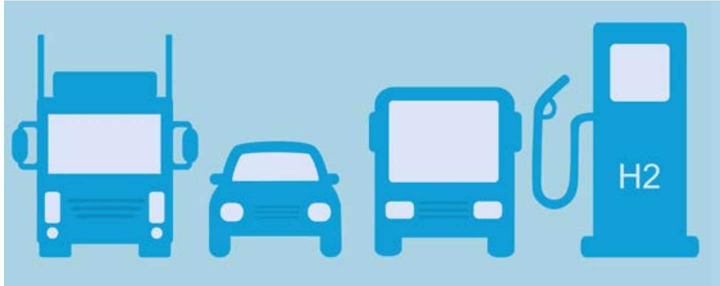


Illustration from iStock, 1347644918

Type	Company	Model	Engine (kW)	Lithium Ion (V)	Mileage (avg.)	Range (mi)	Seating Capacity	Price ($)
Sedan	Toyota	Mirai	134	311	64–74	402	5	$49,500
	Honda	Clarity	130	346	68	300	5	$58,490
SUV	Hyundai	Nexo	120	240	57	370	5	$58,300
Bus	ENC AXESS-FC	-	150–200	-	-	-	43	-
	New Flyer	Flyer Xcelsior CHARGE - 60	734–1,030	-	-	370	40–52	~$1,200,000
	BYD	K-series	180–360	-	-	210–315	13–55	~$1,000,000
	Hyzon	Floor Coach	195	-	-	250	-	-
Truck	Hyzon	Class 8	450	650	-	500	-	-
	Hyzon	Refuse	360	-	-	125	-	-
	Hyundai	Xcient	180	-	-	400	-	-

Note: This list is not comprehensive but provides an overview for the technology. The product spectrum might change from what is listed here.

Hydrogen Storage and Refueling Station

- The level of compression needed at hydrogen fueling stations depends on the pressure required by the fuel cell electric vehicles.
- Available fuel cell electric buses in the United States are pressurized to 35 MPa, and some outside the United States use 70-MPa pressurization.

- Hydrogen fueling stations can be leased or purchased from the hydrogen supplier.
- Stations in California have usually been purchased, and additional maintenance contractors are engaged for station operation.

Hydrogen Fueling Station Capabilities and Costs

Transit Agency	Dispensers	Liquid Storage	Year Built	Estimated Station Cost (millions)
AC Transit Oakland	2	9,000 gallons	2014	$6.3
AC Transit Emeryville	–	9,000 gallons	2011	$5.1
AC Transit Emeryville	2	15,000 gallons	2020 upgrade	$4.424
OCTA	2	18,000 gallons	2019	$4.7
SunLine	2	–	2019	$8.3
SARTA	1	9,000 gallons	2017	$2.9
Foothill Transit	–	5,000 kg	2022–2023	$6.6

The operational cost of the stations varies at around $10,000–$15,000 USD per month.

- On-site hydrogen production by electrolysis or steam methane reforming adds cost to the station with additional infrastructure and associated maintenance.
- On-site production also can contribute to achieving carbon-neutrality goals or regulations.

Note: This list is not comprehensive but provides an overview for the technology. The product spectrum might change from what is listed here.

Tools and Resources: Tools From NREL (Electrification)

EVI-X

- ✓ NREL's modeling suite informs the development of large-scale EV charging infrastructure deployments.
- ✓ Identifying the number and type of chargers needed to meet a given demand.
- ✓ Designing station with sizing, on-site energy storage requirement, load profiles, etc.
- ✓ Assess the economic aspects (e.g., levelized cost of charging).

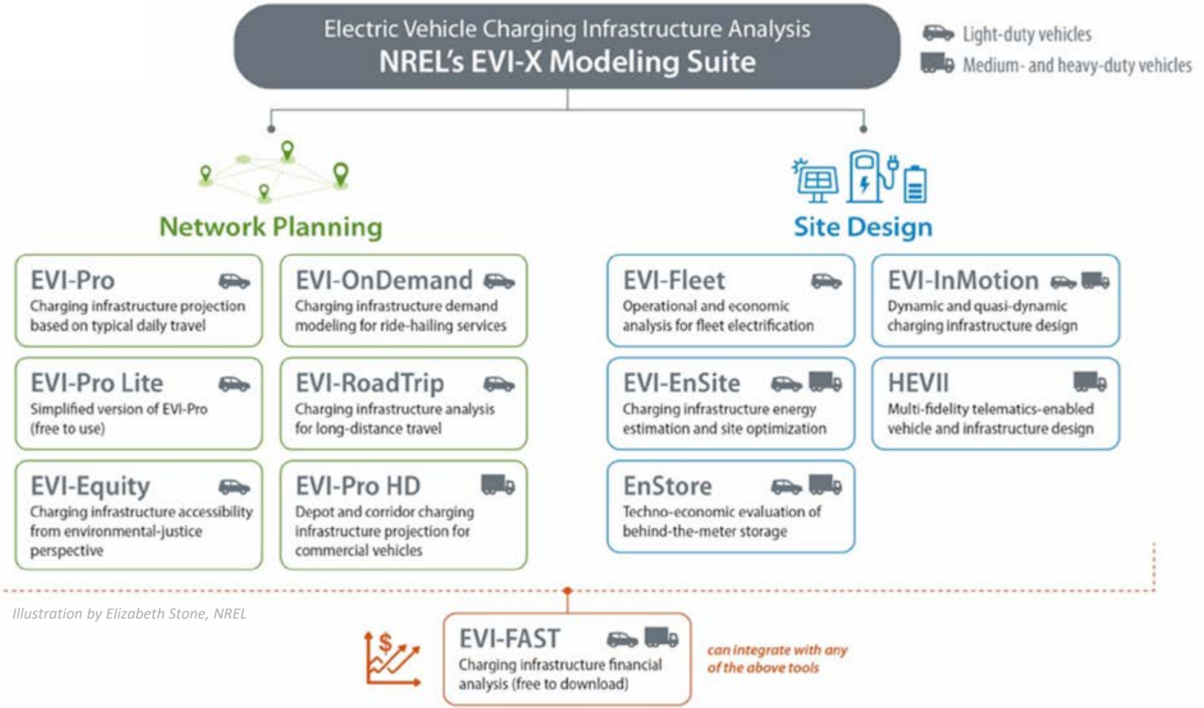


Illustration by Elizabeth Stone, NREL

Use of these tools helps pinpoint efficient charging station locations and find ways to mitigate the impact of charging loads on the electric grid—by tapping into renewable energy and employing smart-charge technologies.

Tools and Resources: Tools From NREL (Electrification)

EVI-X

All available NREL tools are listed here → https://www.nrel.gov/research/data-tools-alpha.html

	Tool	Description	Airport Fleet Analysis Application
1	**EVI-Pro/EVI-Pro Lite**	Determines charge demand based on input travel data, models EVSE deployment needs based on input travel needs with respect to both location and time.	Airport power distribution system can be determined using this tool.
2	**EVI-ProHD**	Oriented toward MHD and heavy-duty commercial vehicles, charging infrastructure to support the use case.	Airport fleet has several MHD vehicles to be electrified and thus matches the use case of the tool.
3	**EVI-EnSite**	Models high-power charging station operation and residential charging profile allocation, generates several load and performance metrics; optimizes site operation.	Optimization of airport charging station and number of ports for each EVSE.
4	**EVI-Fast**	Estimates break-even price to charge EVs based on input parameters such as installation costs, operation maintenance, utilization, grid-infrastructure upgrades.	For planning the electrification blueprint assessing economic factors and grid upgrade requirements.
5	**EVI-Edges**	Identifies the optimal design and energy flows for thermal and battery behind-the-meter-storage systems based on climate, building type, and utility rate structure.	Can be used for efficient energy storage incorporation with the current airport infrastructure.
6	**EVI-InMotion**	This tool is used for planning, optimizing, and analyzing the feasibility of charging EVs while driving on electric roads.	Applicable if dynamic/quasi-dynamic charging module for fleet vehicles are considered.
7	**FASTSim**	Provides a simple way to compare powertrains and estimate the impact of technology improvements on light-, medium-, and heavy-duty vehicle efficiency, performance, cost, and battery life.	Applicable for comparative economic assessment of different fleet vehicles and evaluating the battery life.

Tools and Resources

EV Fleet Programs

PG&E EV Fleet Program

- Incentives and rebates
- Site design
- Construction
- Maintenance and upgrade.

Microgrid Labs

- EVOPT controller and EVOPT planner
- Site design
- Construction
- Optimization
- Financial analysis.

AFLEET

- xls.-based tool
- Fleet footprint analysis
- EV charging
- Transit cost analysis
- Emissions calculation.

Transportation and Fleet Behavior

- MATSim
- SUMO
- TRANSIMS

These platforms provide features to model and analyze agent-based transportation systems.

Power System Analysis

- OpenDSS
- Powerfactory
- MATLAB
- Cyme (Eaton)
- Synergi (DNV)
- GridLabD (Pacific Northwest National Laboratory)

These platforms provide features to analyze the impact of electrification on the distribution network and grid.

Hydrogen

H2FAST

- Hydrogen Financial Analysis Scenario Tool; provides in-depth financial analysis for hydrogen fueling stations.

GT Suite

- Design, model, and optimize all applications in the hydrogen mobility sector.

These platforms provide features to analyze the hydrogen and fuel cell-based systems model development and financial analysis.

Tools and Resource: Knowledge Base for the Future

Training

- ✓ This list of on-demand training opportunities covers a wide variety of content on EVs.
- ✓ Completing the items on this list will provide fleet and facility managers with all the information necessary to plan, design, and execute a successful fleet electrification program.
- ✓ Knowledge base caters to both EV novices and experts.

Photo from iStock, 1402737190

Federal Fleet EV Training Materials FY 2022

TRAINING	TYPE	DURATION	SUBJECT AREA AND LEVEL
☐ FEMP EV Technology Overview	Video	12 minutes	EV 101, EVSE 101
☐ FEMP EV Financial Considerations	Video	9 minutes	Financial 101
☐ FEMP Electric Vehicle Supply Equipment Infrastructure	Video	8 minutes	EVSE 101, Facility 101
☐ Charging GSA Fleet EVs Publicly	One Page	~5 minutes	EVSE 101
☐ GSA ZEV Fact Sheet and AFV Guide	Website	~30 minutes	EV 101
☐ Attend EV Champion Training 1: Technology & Financials	CEU Webinar	91 minutes	EV 102, EVSE 102
☐ Attend EV Champion Training 2: EVSE Power/Install	CEU Webinar	68 minutes	EVSE 201, Facility 201
☐ Attend EV Champion Training 3: EV Site Assessments	CEU Webinar	127 minutes	EVSE 202, Facility 202
☐ Attend EV Champion Training 4: Advanced EV Solutions	CEU Webinar	121 minutes	Facility 301, Program 301
☐ EV Champion Worksheet 1: Technology & Financials	Worksheet	~30 minutes	EV 201, Financial 201
☐ EV Champion Worksheet 2: EVSE & Electric Utility	Worksheet	~30 minutes	EVSE 201, Facility 201
☐ EVSE Tiger Team Report: Army Site Assessments	Report	~45 minutes	EVSE 201, Facility 201
☐ Workplace Charging Program Guide	Report	~45 minutes	Program 201, Financial 201
☐ Workplace Charging Fee Calculator	Calculator	~10 minutes	Program 202, Financial 202
☐ Vehicle Cybersecurity Threats and Mitigation Techniques Report	Report	~45 minutes	EV 301, EVSE 301
☐ GSA Fleet Workshop: EVs and EVSE	Video	71 minutes	EV 101, EVSE 101
☐ Future GSA Fleet Workshop Trainings	Website	~60 minutes	Various
☐ Fed Fleet: Fleet Analysis for EV Suitability	Slide Deck	~30 minutes	EV 201
☐ Fed Fleet: EVs and EVSE	Slide Deck	~30 minutes	EV 201, EVSE 201
☐ ZPAC Training Series	Video	45 minutes	EV 202, EVSE 202

https://www.energy.gov/sites/default/files/2021-10/federal-fleet-ev-training-materials-fy22.pdf

Additional EV and Fuel Cell Vehicle Information and Resources

Alternative Fuels Data Center

- Electric Vehicles for Fleets – https://afdc.energy.gov/vehicles/electric_fleets.html
- Fuel Cell Electric Vehicles – https://afdc.energy.gov/vehicles/fuel_cell.html
- Model Year 2022 Alternative Fuel and Advanced Technology Vehicles – https://afdc.energy.gov/vehicles/search/download.pdf?year=2022

Hybrid and Zero-Emission Vehicle Incentive Program (HVIP)

- HVIP Eligible Vehicles – https://californiahvip.org/vehiclecatalog/

Southern California Edison – Charge Ready Transport Program

- Tools & Resources - https://crt.sce.com/resources

National Renewable Energy Laboratory

- Fuel Cell Electric Bus Evaluations – https://www.nrel.gov/hydrogen/fuel-cell-bus-evaluation.html
- Safety, Codes, and Standards – https://www.nrel.gov/hydrogen/safety-codes-standards.html
- Commercial Vehicle Technologies – https://www.nrel.gov/transportation/commercial-vehicle-technologies.html
- Fleet DNA – https://www.nrel.gov/transportation/fleettest-fleet-dna.html

U.S. Department of Energy

- Vehicle Technologies Office – https://www.energy.gov/eere/vehicles/batteries-charging-and-electric-vehicles
- Hydrogen and Fuel Cell Technologies Office – https://www.energy.gov/eere/fuelcells/technology-validation

Recommendations for Follow-On Detailed Analysis

Ontario Airport EV blueprint would benefit from additional fleet/vehicle data collection and analysis to better define load profiles and deployment priorities based on duty cycles.

- ***Fleet Inventory Energy Consumption and Usage***
    - Fleet inventory and usage statistics
    - Energy breakdown by vehicle types and departments
    - Vehicle energy requirements/duty cycle analysis
    - Fleet replacement criteria—vehicle age/mileage
    - Selection of priority electrification candidates
    - Detailed data collection on priority vehicles.
- ***Infrastructure Requirements***
    - Priority charging locations
    - Vehicle dwell times and fleet parking locations
    - Utility rates/rate structures.
- ***Cost of Operation/Ownership Evaluation***
    - Cost data collection (fleet)—fuel cost, electricity cost, maintenance
    - Cost data collection (market)—fuel cost, electricity cost, maintenance
    - Cost calculations—e.g., Vehicle Infrastructure Cash-Flow Evaluation (VICE) tool.

Thank You!

www.nrel.gov/transportation

NREL/PR-5400-85482

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