



# Grid Integration of Sustainable EV Charging Systems

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Adel Nasiri, CEO, Imagen Energy, LLC, Since April 2017  
Distinguished Professor, University of South Carolina, Since Aug 2021

Grigg Chair Professor, University of Wisconsin Milwaukee, 2005-2021  
Fellow IEEE

Research Interests: High power converters, energy storage system, electric vehicles, grid-connected power electronics, resilient energy systems



Chair, IEEE IAS Renewable and Sustainable Energy Conversion Systems, 2019-2020.

Vice-Chair, IEEE IAS Technical Committee on Sustainable Energy Systems, 2021-

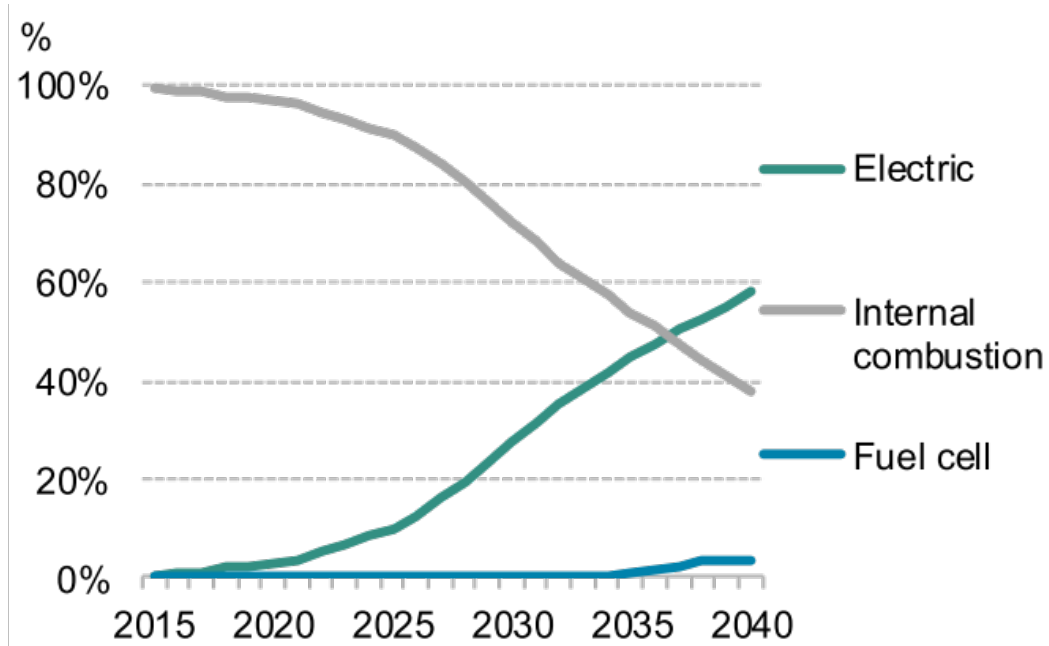
Paper Review Chair, IEEE Transactions on Industry Applications, Renewable and Sustainable Energy Conversion Committee, 2018-2019.

Editor, IEEE Transactions on Smart Grid, 2013-2019.

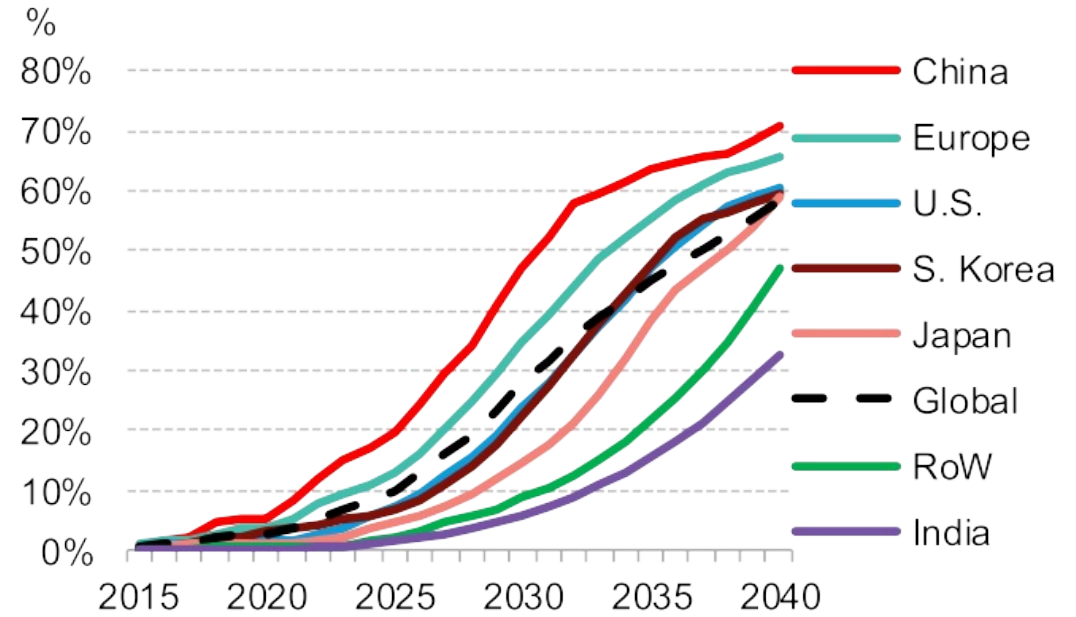
Editor, Journal of Electric Power Components and Systems, 2015-.



# Projected Annual Sales of EVs



Global share of total annual new passenger vehicle sales by drivetrain.



Global long-term EV share of total annual passenger vehicle sales by region.

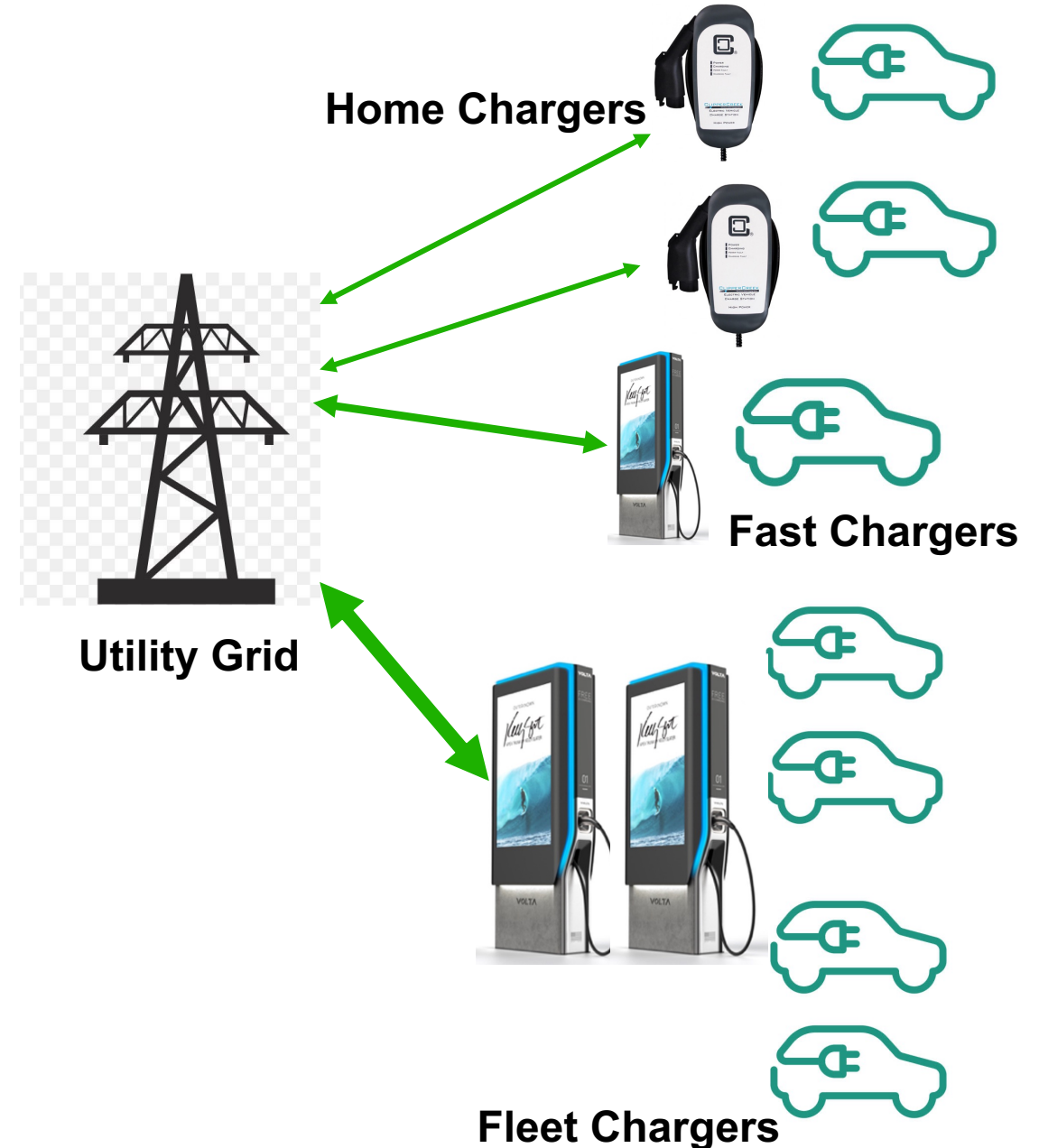
Based on 2019 numbers, 10.2 million vehicles will be sold in the US in 2040. This does not include buses and large trucks.

Source: Bloomberg 2020 Electric Vehicle Outlook.



# V2G: Missing Piece of the Smart Grid Infrastructure?

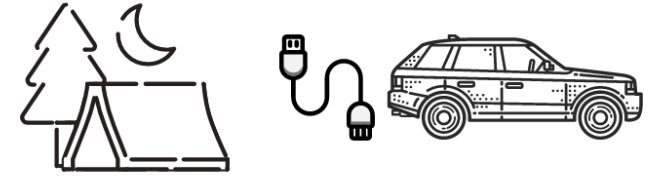
- Electrical energy storage can enable the concept of smart grid, integrate renewables, improve reliability, increase flexibility, and lower energy cost.
- EVs are energy storage systems on the move.
- In 2020, there were 287 million cars in the US. If half of the total vehicles are electric, and
  - If each car has a 75kWh of battery,
  - We will have a total of 10,750 GWh of energy storage.
- US has an electricity generation capacity of 1,120 GW
- 9.5 Hours of charge!!!



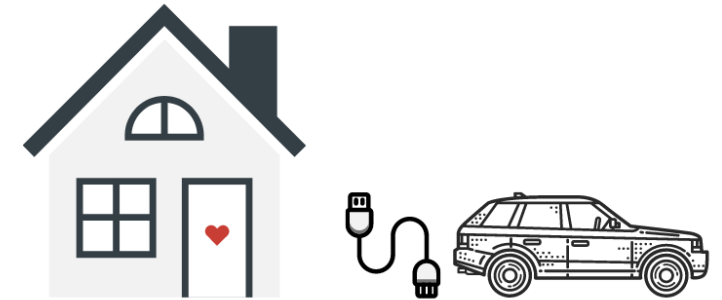
# State of Art

- V2L will be available on most upcoming cars.
- V2H will also be available (grid disconnect must be open).
- V2G is more complicated:
  - Not monetized, coordination with DSO, ISO
  - Needs grid regulations including protection and safety
  - Needs vehicle side communication and standards
  - Will vehicles cooperate?

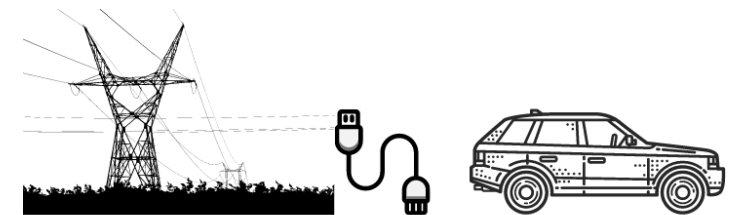
## **VEHICLE TO LOAD**



## **VEHICLE TO HOUSE**

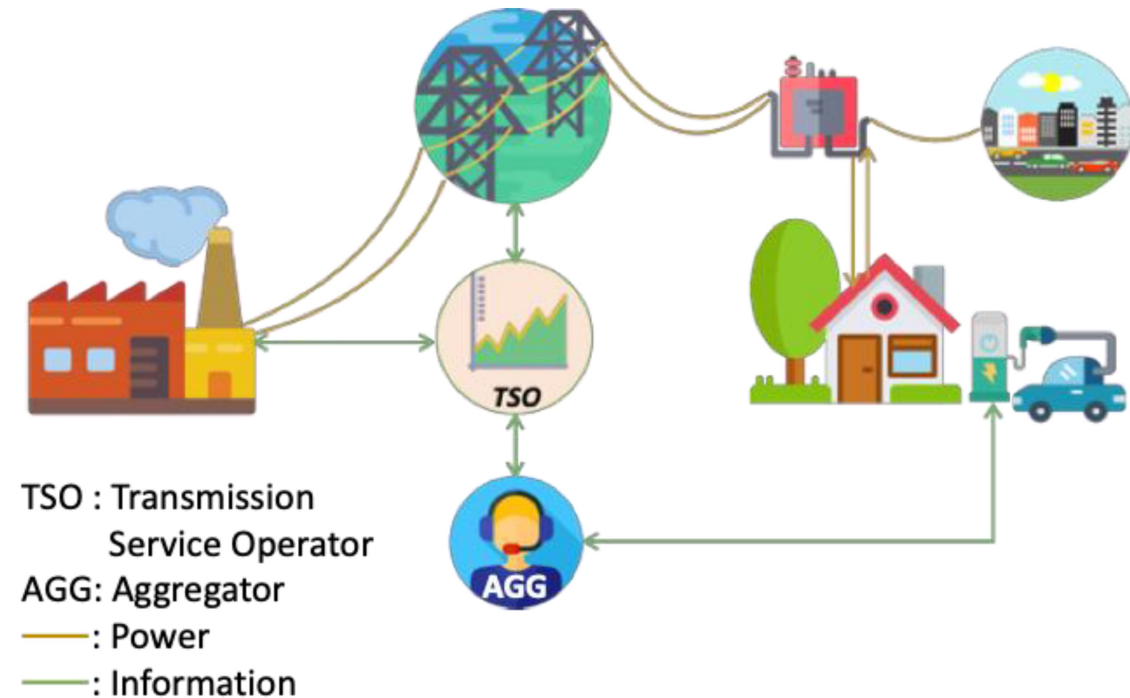


## **VEHICLE TO GRID**



# What V2G Can Offer

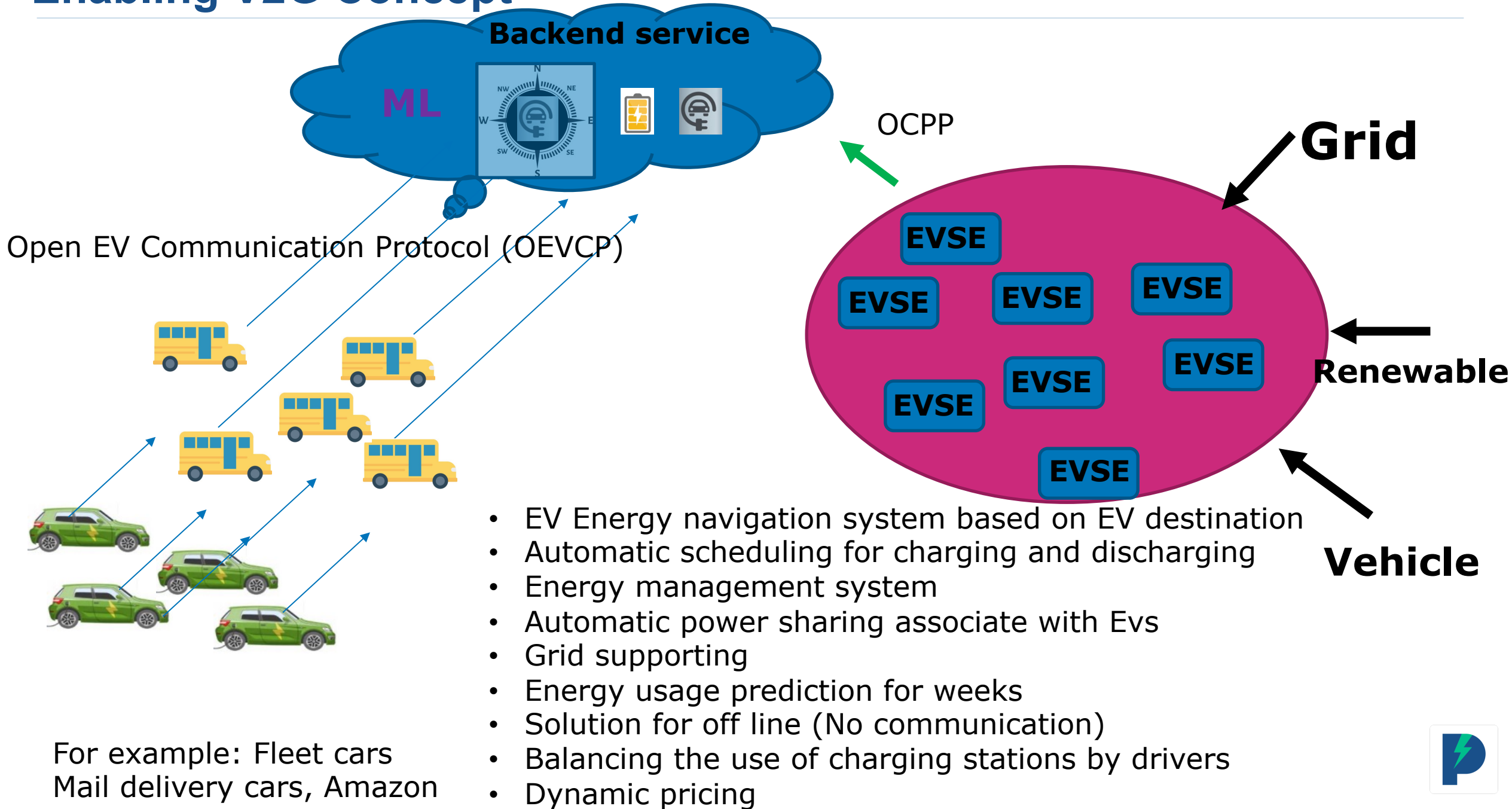
- Energy arbitrage with grid
- Demand response
- Ancillary services
- Grid frequency support
- Spinning reserve
- Renewable firming
- Suppress transient events
- Dampen damage and support recovery after natural disaster
- Off-grid and microgrid operations



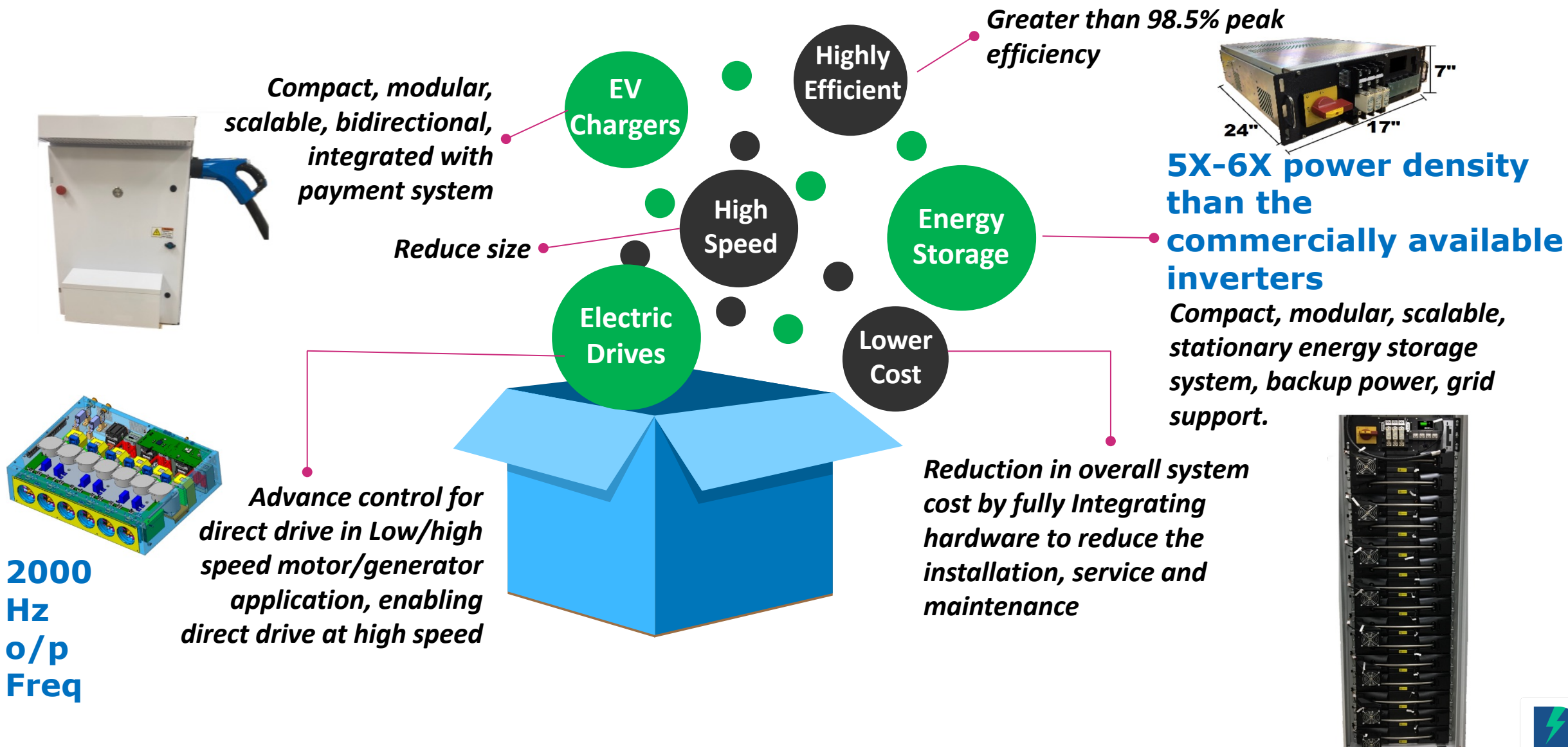
*Muhammad Huda et al. Energies 2020, 13(5), 1162*



# Enabling V2G Concept



# Imagen's Product and Solution Offering





# Competitive Landscape and Unmatched Power Density for DC Fast Chargers(DCFC) EV Charging Infrastructure



40"W x43"D x96"H  
[101cmx109cmx243cm]

**NO Isolation Transformer, but  
Includes 160kWhr Battery.  
Input Power Limited to ONLY 27kW**

**\*In Scale Size Comparison**



38"W x30"D x82"H  
[96cmx76cmx208cm]

**Integrated 60 Hz Low  
Frequency Isolation  
Transformer**



31"W x27"D x70"H  
[80cmx70cmx180cm]

**Integrated 60 Hz Low  
Frequency Isolation  
Transformer**



Imagen 100kW  
24"W x12"D x35"H  
[60cmx30cmx88cm]

**Integrated 100 kHz High  
Frequency Isolation  
Transformer**

**Extremely compact solution enables opportunities for multiple charging stations where space is limited and costly.**



# Key Technology Enablers/Features for Compact DCFC Stations

## IM100 AC-DC Converter



- Integrated Compact Bi-Directional Converter
- Compact size: 17"x24"x7"
- Rated @100kW
- Provide High Voltage 850VDC Bus for EV100s
- Efficiency at full load >98.5%
- Exceeds Power Quality Std @ POCC

## EV100 Isolated DC-DC Converter



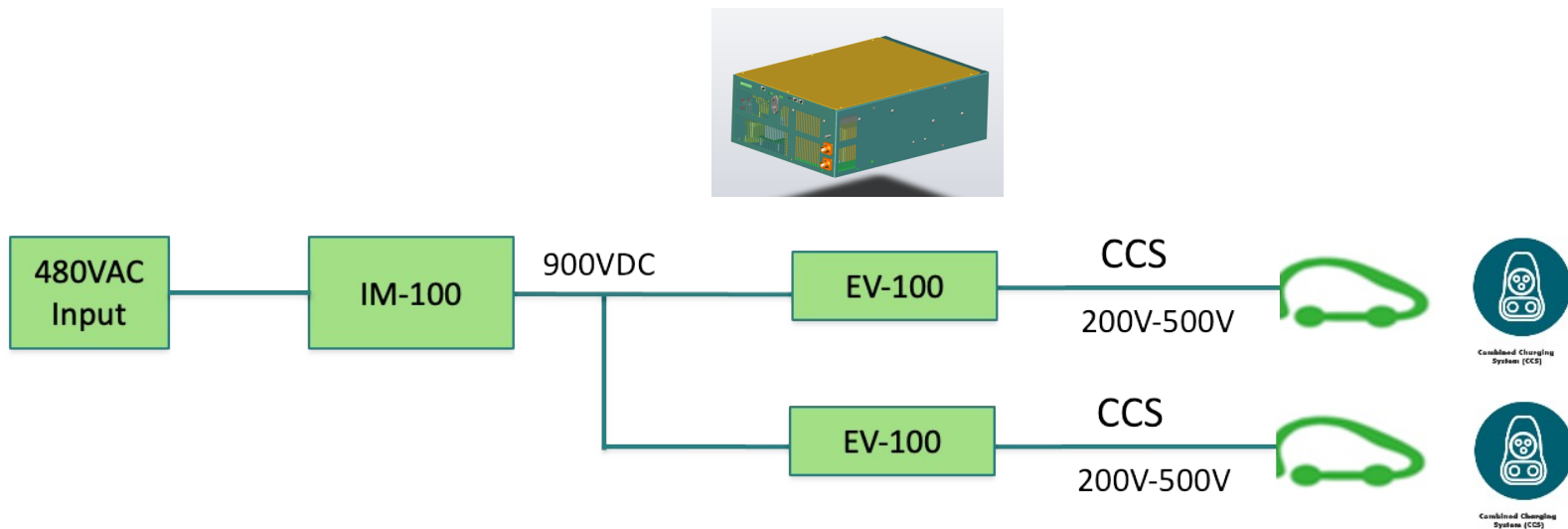
- Compact Bi-Directional DC-DC rated at 100 kW
- SiC Technology with >100 kHz switching
- High Frequency Isolated Transformer
- Compact size: 14"x17"x7"
- Ability to Provide DC Fast Charging (DCFC)
- Future proof hardware
- Advanced Resonant Based Control
- Efficiency at full load ~99%

**Both IM100 and EV-100 are Bi-directional and therefore able to support V2G/B2G applications**

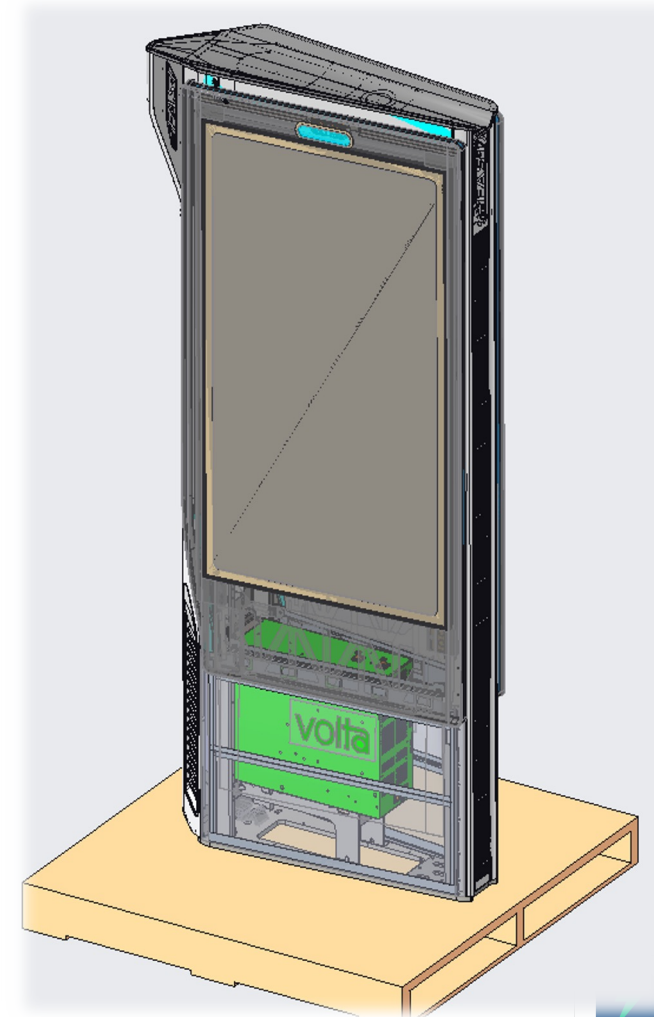


# 100kW Bi-Directional DCFC Stations

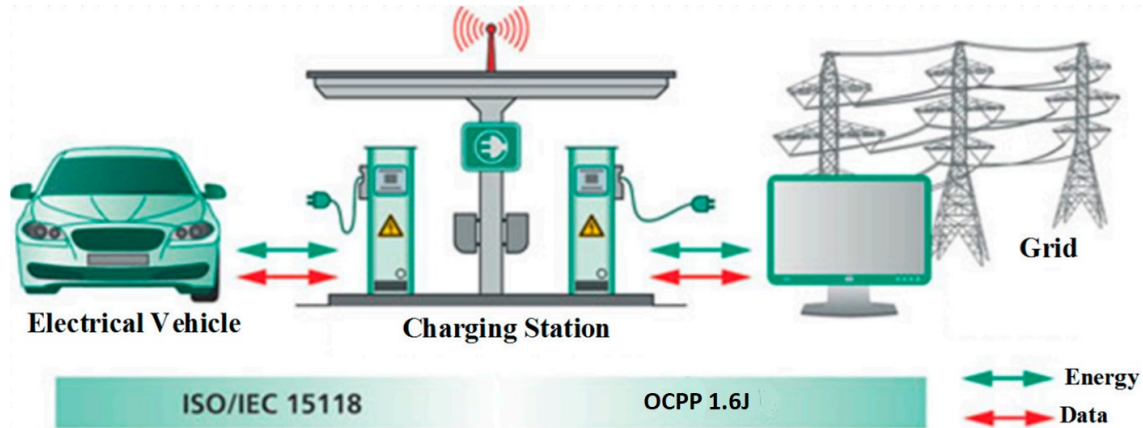
- EV100 includes high frequency isolation transformer
- Volume ~27 Liters envelop
- Modular design with multiple charging stations
- Enable high resolution load balancing between EVs
- Currently under review for UL2202 and UL2231 certifications
- Start of production Q3-2022



Property of Imagen Energy, LLC



# Compliant Software Stack



## Software Stack ISO 15118 consists of:

- Support of Value-added services (VAS)
- Support of External Identification Means(EIM)
- Support of Plug and Charge (PnC)

## Software stack OCPP(Open Charge Point Protocol)

- Support of Certificates, loading profiles and customer-specific messaging.
- Currently support OCPP 1.6J



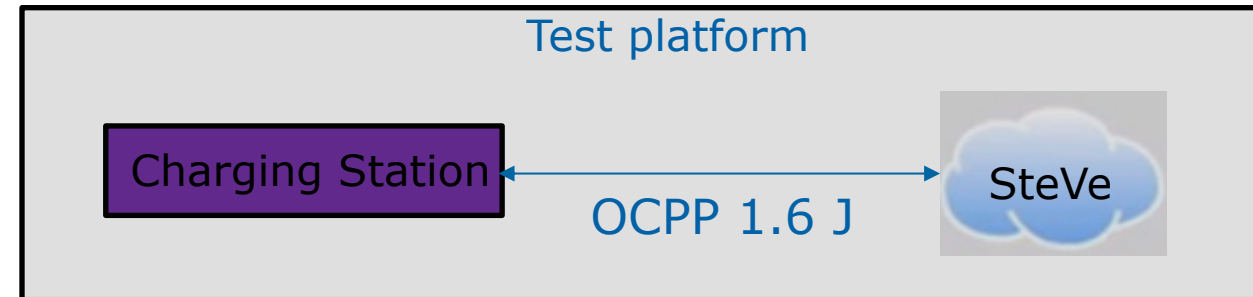
# Open Charge Point Protocol (OCPP)



OCPP is an open-source communication standard for EV charging stations and network software companies

- Charging session authorization
- Collecting billing information
- Discovery and reservation of EVSE
- Real time charging session data transfer to CSMS
- Real time status stations
- Remote charging session control
- Firmware management
- Fault Diagnosis
- Smart
- Charging
- Cyber
- security

Drivers to roam between charging networks without needing separate memberships.



- CSMS Charging Station Management System
  - SteVe is considered as an open platform to implement, test and evaluate OCPP protocol

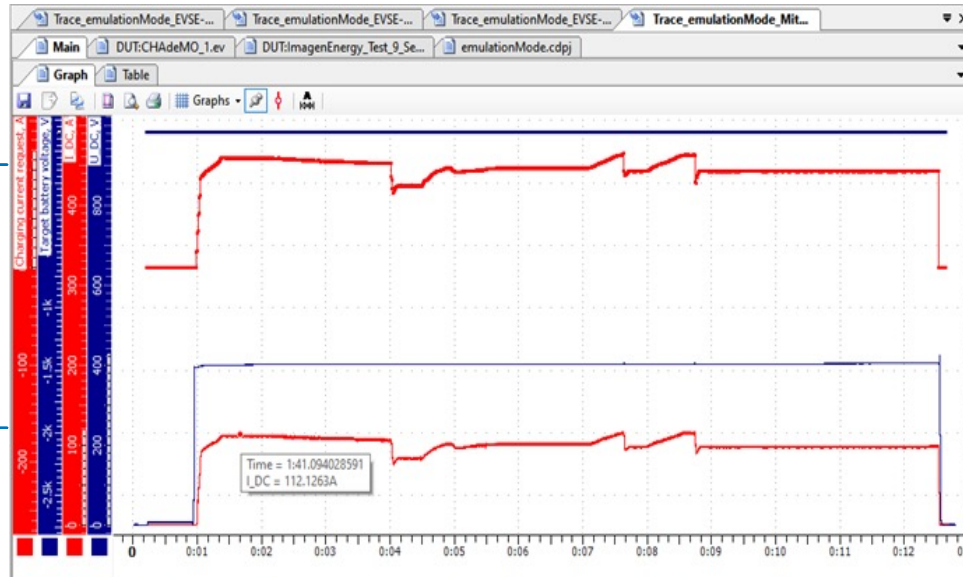


# Validation Test using Multiple Vehicles, Tesla Model 3 and Chevy Bolt

Voltage/Current waveform captured during charging using Keysight charge discovery equipment

Request from EV

Response From EVSE



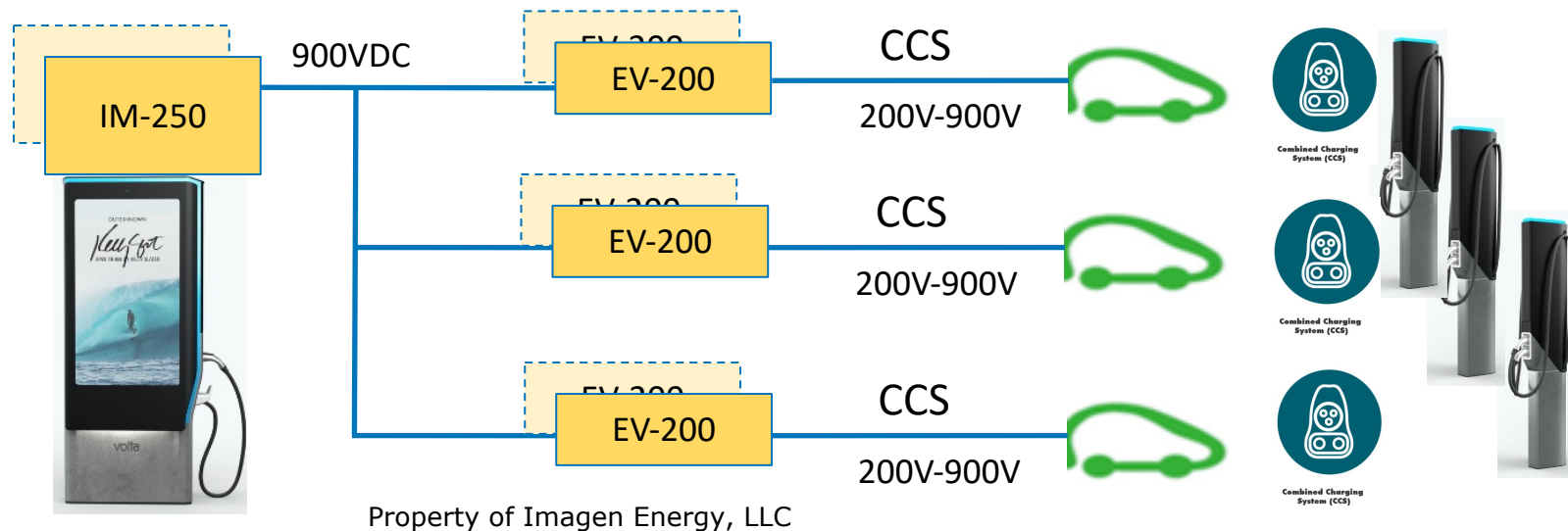
Demonstrated charging different EVs.  
Demonstrated load balancing and prioritization.  
Maximized available energy utilization.  
Tight response to changing vehicle request

## Simultaneous Charging/load balancing Testing



# 200kW Bi-Directional DCFC Stations

- EV200 includes high frequency isolation transformer
- Volume <30 Liters envelop
- Modular design to support multiple charging stations
- Scalable for increased both **total** capacity and **charging** capacity
- Enable high resolution load balancing between EVs
- Currently under development, regulatory review start Q1, 2022
- Start of production Q2-2023



# Stationary Energy Storage System (ESS-1000)

## Turnkey Solution

- ✓ Fully integrated with battery safety components.
- ✓ Reduced Installation time with minimal connections
- ✓ Includes advance inverter control and BMS
- ✓ Multiple units can be connected in parallel for higher power
- ✓ Allow each battery string to run at its own optimal capacity

## Applications

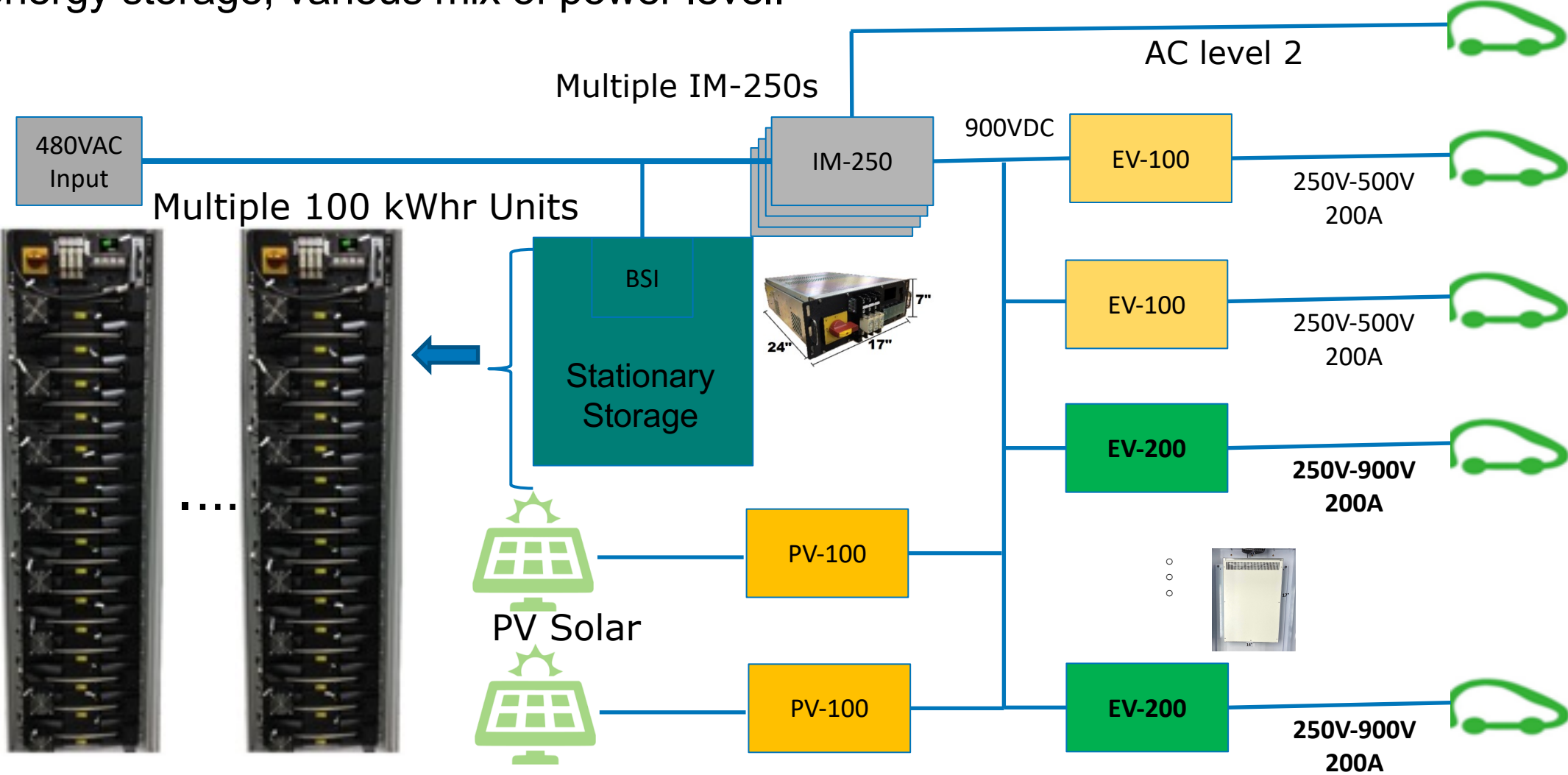
- Energy Storage for Charging Infrastructure support
  - Peak shaving
  - Grid support
  - Backup Power
  - Micro-grid
- Compact Bi-Directional Converter rated at 100 kW (5x)
  - Package Size:17"x24"x7"
  - Energy Storage System Rated @ 100kWhr
  - Operating voltage up to 1000 VDC
  - Efficiency at full load >98.5%
  - Extremely High Power Quality at POCC (2.75% THD)





# Solar and Energy Storage Integrated Charging Stations

- Future fuel stations: Numerous charging points, and large stationary energy storage, various mix of power level.



**200kW based building block is key enabler of future MW charging**



# Imagen's Charging Technology Features

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- ❑ Miniaturizes the large transformer by employing SiC and increasing the switching frequency and enables high frequency isolation .
- ❑ Highly integrated compact design to minimize installation and construction costs.
- ❑ Multiple AC/DC charging outlets in a modular and scalable architecture.
- ❑ Enables wide operating voltage range 200V-900V.
- ❑ Uses bidirectional topology to enable V2L,V2H and V2G features.
- ❑ Allows for easy integration of stationary energy storage and solar PV at DC bus voltage to provide reduce energy cost to customers
- ❑ The technology and IP allows to develop adjacent technologies such as propulsion dives, on-board chargers and DC-DC converters in timely manner to support electrification product platforms



# Conclusions

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- V2G can offer significant benefits to electric utilities, customers and charging stations.
- Regulations and communications for the V2G are being worked out.
- Charging all EVs requires a significant upgrade to utility grid.
- Imagen products are compact and bi-directional and fit for the V2G applications.



# Thank you for your interest.

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