



**KEYSIGHT
WORLD 2019**

Bring Breakthrough Electric Vehicle Innovations to Market Faster

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Keysight's Energy & Automotive Solutions

INNOVATIONS FOR A RAPIDLY GROWING & CONVERGING MARKET

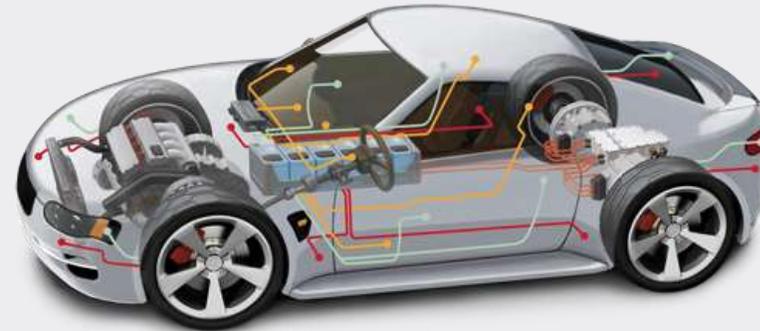
Energy



Distributed generation of energy is driving innovation

- Alternative energy generation
- Smart consumption
- Storage solutions
- New power semiconductor technology

Automotive



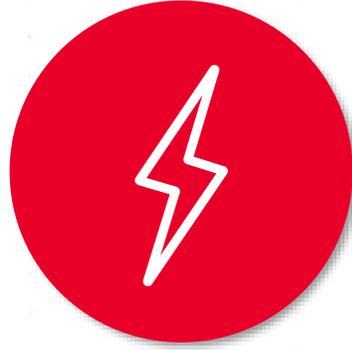
Electrification is occurring at astonishing speed

- Electrical powertrain
- Autonomous driving
- Connected cars
- Infrastructure buildout for power and communication

Agenda



The Adoption of
the Electric Vehicle



The Transformation of
the Energy Industry



EV Technology Advancements
and Test Challenges

The Adoption of the Electric Vehicle



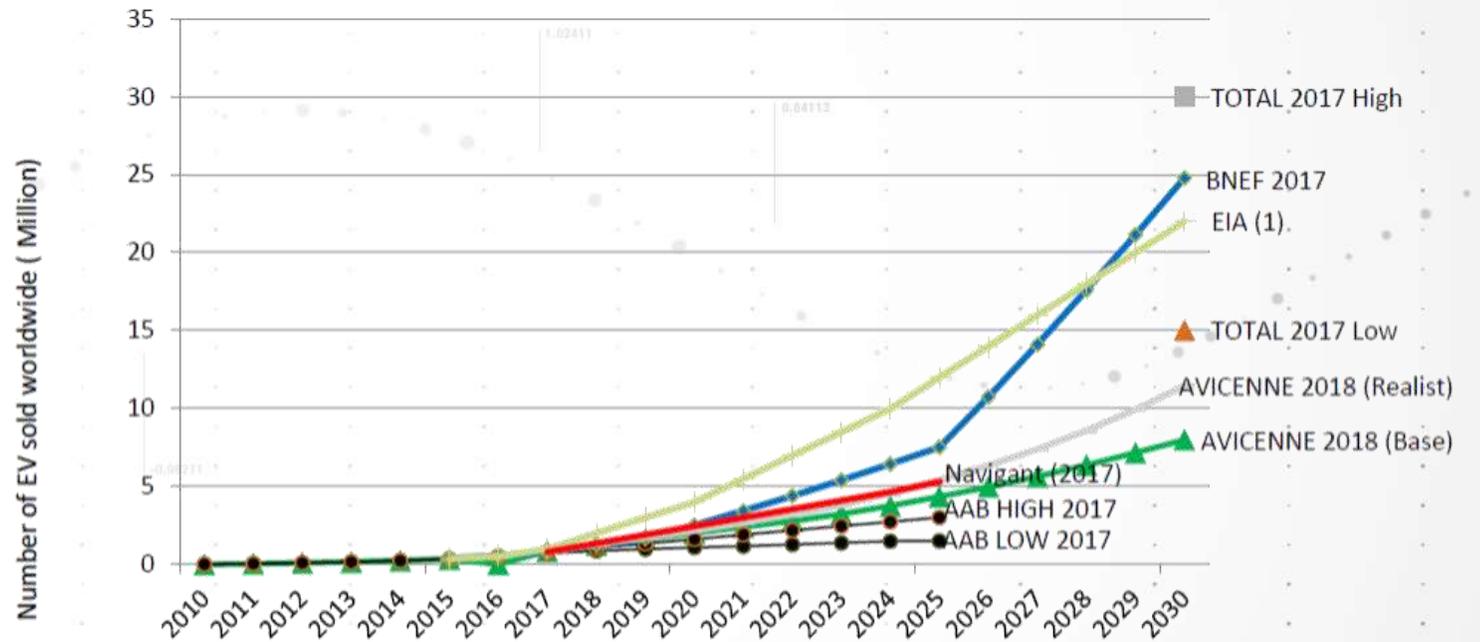
Adoption Of The Electric Vehicle (EV & HEV)

MARKET FORECASTED TO GROW TO >12M UNITS BY 2030

- Battery Technologies are the critical enabling technology.
- Alternative energy generation is required to generate emission free miles.
- Charging Infrastructure needs to be built up broadly.



EV sold, in million units, worldwide, 2010 - 2030



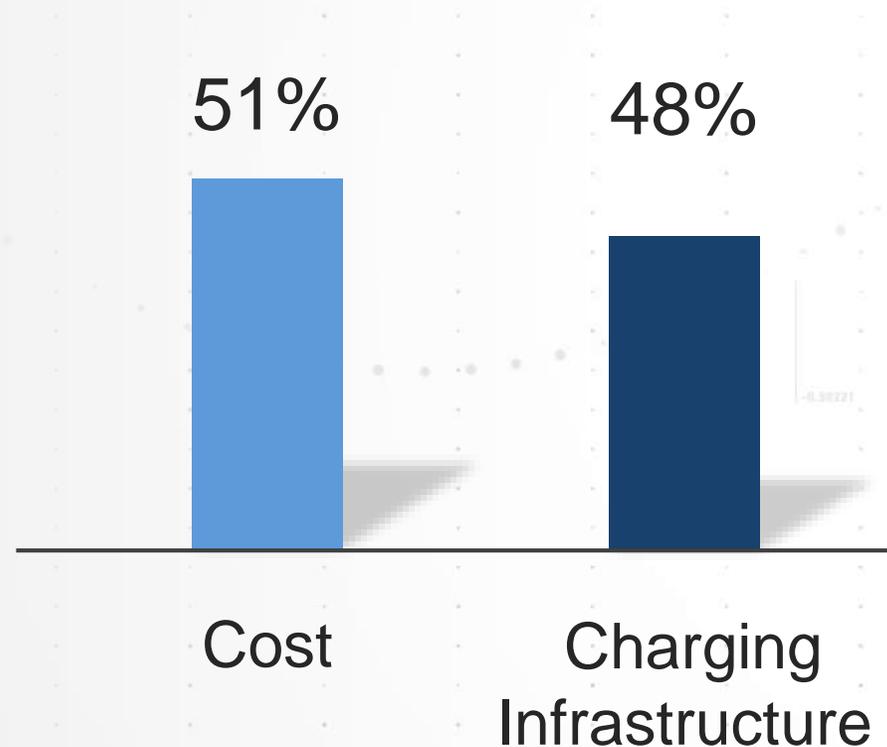
AAB, AABC US, June 2017
BNEF, BATTERIES 2017, October 2017
AVICENNE Analysis 2019

(1) EIA – Avicenne estimation based on “Stock” numbers

Consumer Adoption Of EV Is Still A Challenge

REAL AND PERCEIVED HURDLES TO OVERCOME

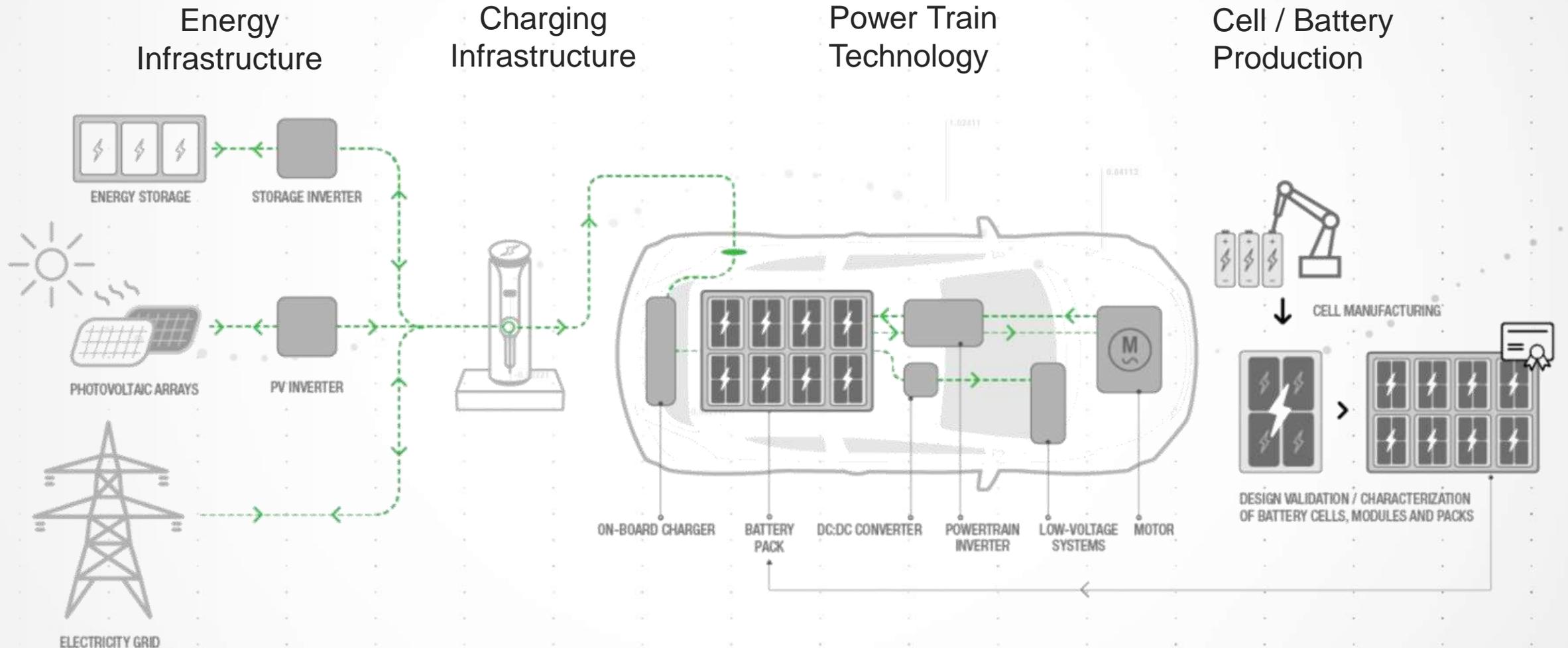
Why would you NOT consider buying or leasing a plug-in electric vehicle?



- **51%** of consumers believe EVs are **Too Expensive**
- **48%** struggle with the **Charging Infrastructure**
- **Median EV range** of **300 miles** is necessary for consumer acceptance

Electric Vehicles Drive Technology Investments

MARKET DRIVERS APPLY PRESSURE ON THE EV ECOSYSTEM



The Transformation of the Energy Industry



Readying The Grid For The EV Revolution

TRENDS SHAPING THE FUTURE OF ELECTRICITY

EVs are adding **3,461TWh of new electricity demand** by 2050!

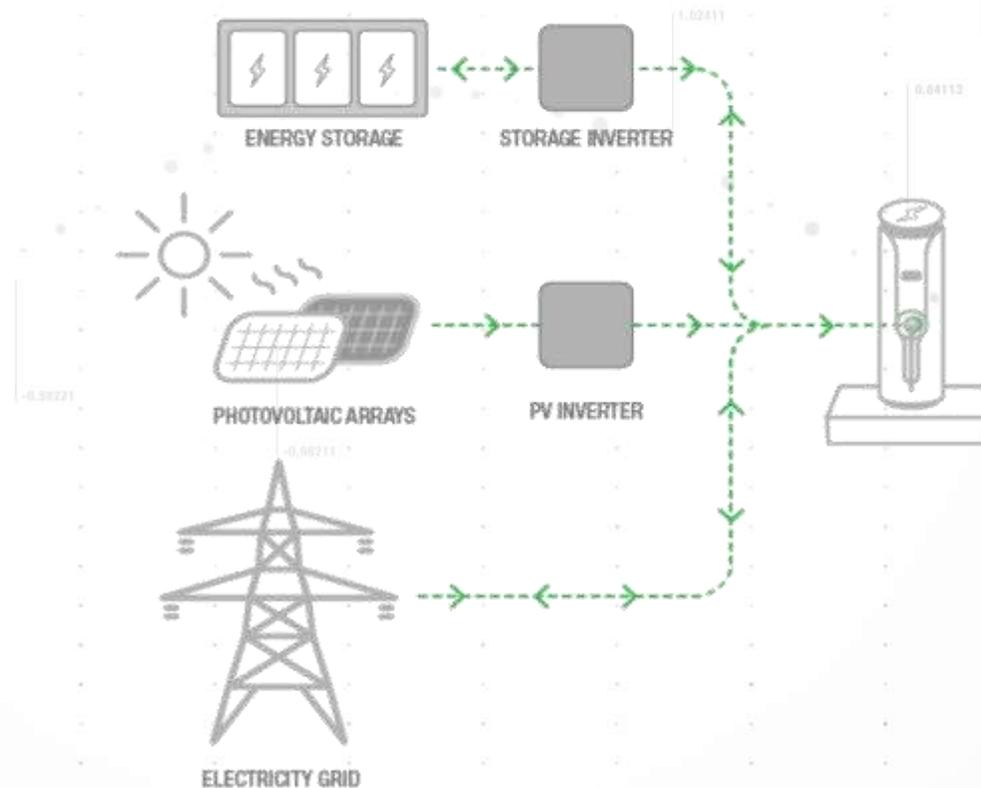
(Bloomberg)

\$548 billion investment in **grid-tied battery storage** 2018-2050

(Bloomberg)

\$11.5 trillion investment in **renewables** 2018-2050

(Bloomberg)



Vehicle Electrification Transforming The Energy Industry

CRUCIAL ELEMENTS OF THE EV REVOLUTION



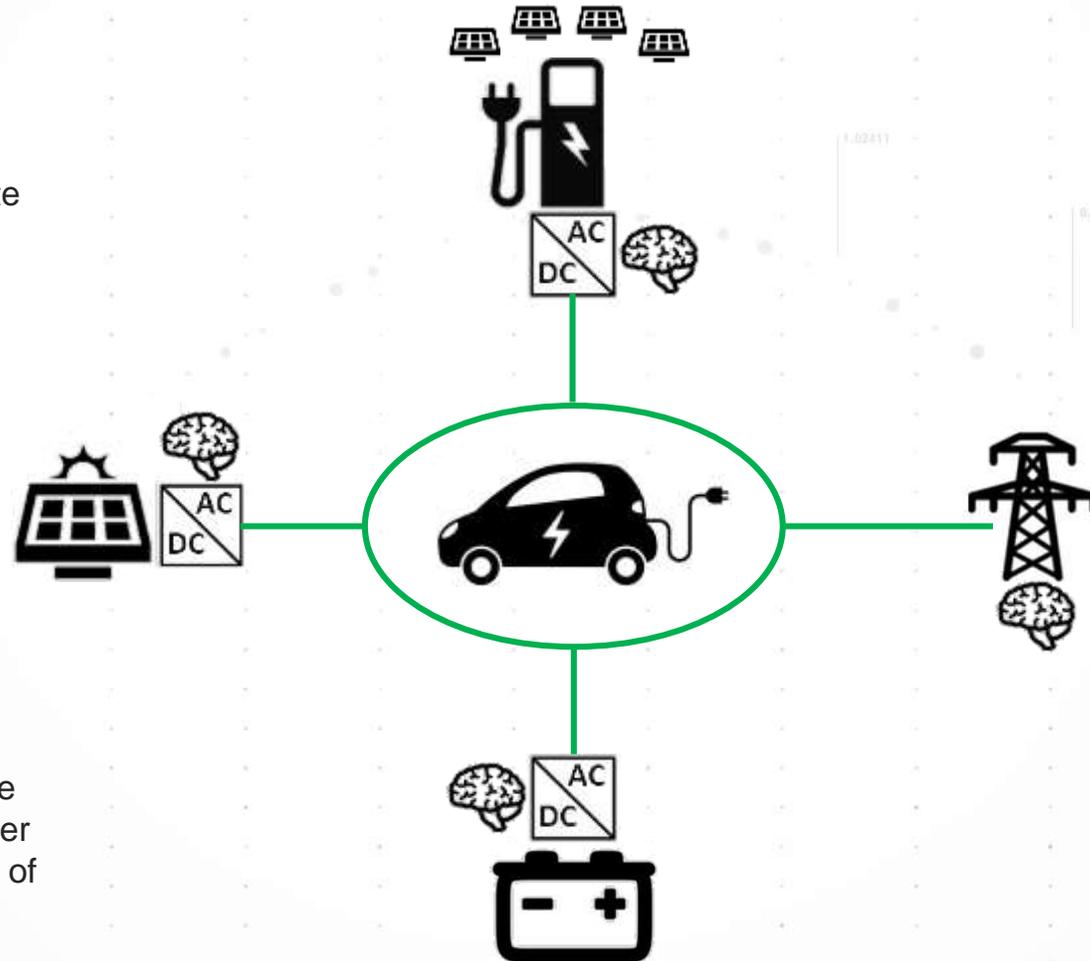
DECARBONIZATION

Regional policies pushing to accelerate availability of cheap electricity from renewables



SECTOR COUPLING

Additions of energy storage to balance supply / demand, increase overall power system efficiency and reduce total cost of EV ownership



DECENTRALIZATION

Distributed energy resources (DER) such as PV help meet EV electricity demand while deferring expensive grid upgrades for charging infrastructure development



GRID INTEGRATION

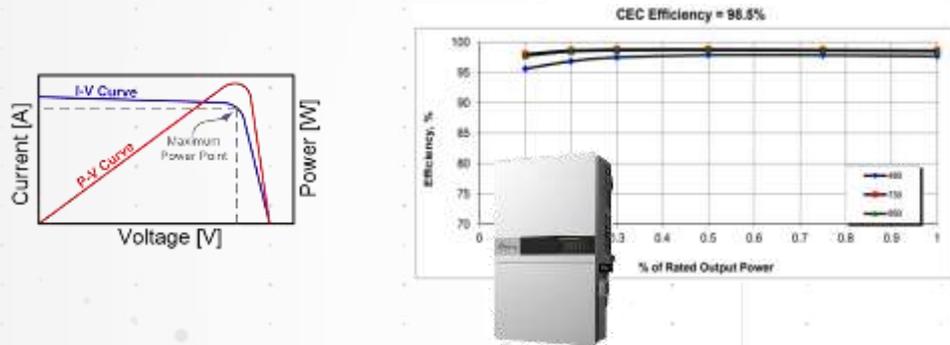
Coordinated interoperability to maintain grid reliability as penetration of variable energy resources increases

Innovations At The Grid Edge

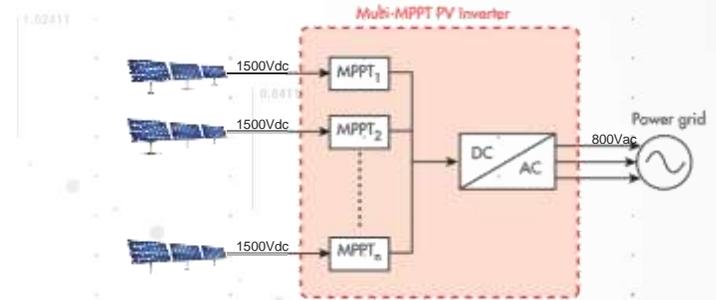
NEW CHALLENGES FOR DEVELOPERS OF GRID-TIED POWER CONVERSION SYSTEMS



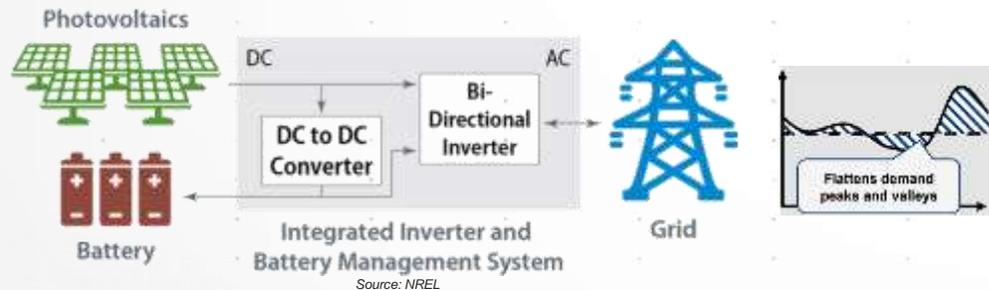
Maximizing efficiency / increasing performance bankability to reduce the total cost of solar



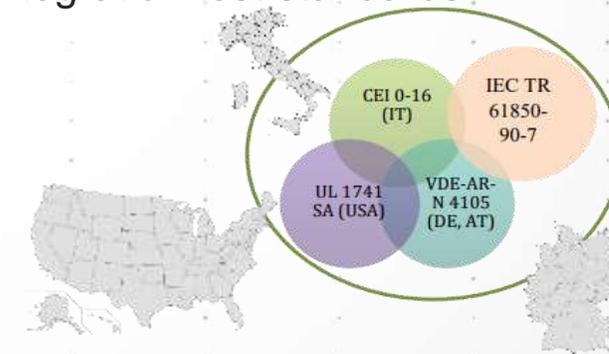
Characterizing performance of new multi-string PV inverters with higher AC+DC voltages and several internal maximum power point trackers



Testing high-voltage energy storage systems and PV+storage inverters with bi-directional power flow



Verifying new smart inverter grid support compliance with regional grid codes / constantly changing grid integration test standards



Accelerating And Optimizing New Grid-Tied PCS

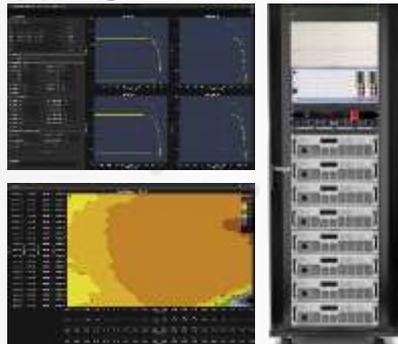
LOWER COST, FASTER TTM, INCREASED PERFORMANCE



CHALLENGE

Maximizing efficiency and performance bankability

PV Inverter Efficiency Mapping Characterization



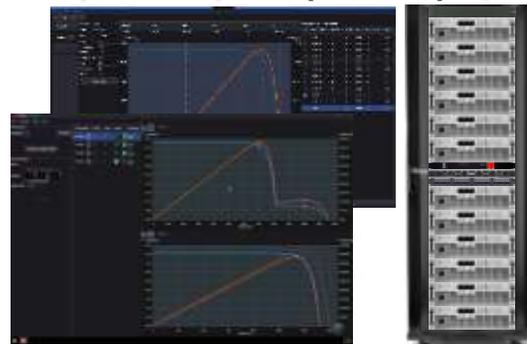
Better / faster efficiency characterization, higher energy yields, increased bankability



CHALLENGE

Test complexity for multi-string PV inverters

Distributed Solar Array Simulation (D-SAS)



Reduced complexity, faster testing, more realistic test cases



CHALLENGE

Bi-directional battery and PV+storage inverter testing

High-Voltage Regenerative Battery+PV Simulator



Universal DER simulation, reduced energy consumption / cooling



CHALLENGE

Verifying smart inverter grid support functions

High-Voltage 4-Quadrant Regenerative Grid Simulator



Programmable emulation of grid codes / standards, reduced energy consumption / cooling

BENEFITS

Lower cost
Faster time-to-market
Increased performance / reliability

EV Technology Advancements and Test Challenges



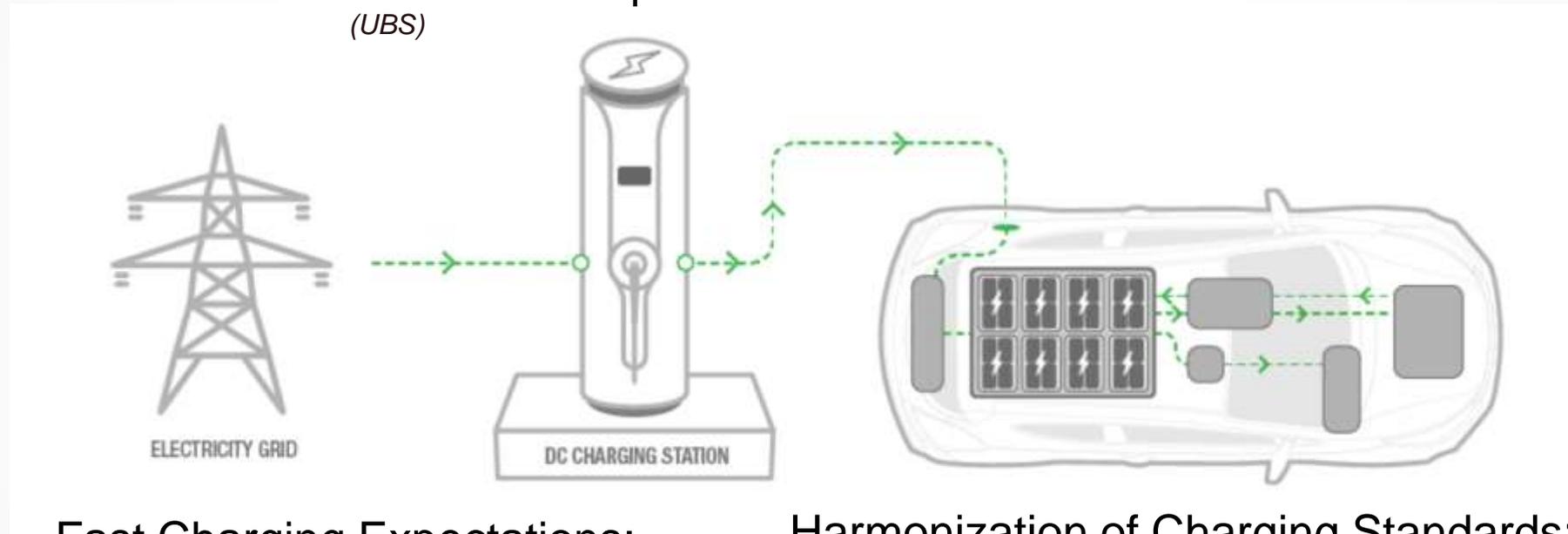
Electric Vehicles Drive Technology Investments

INFRASTRUCTURE CHALLENGES: INTEROPERABILITY AND CONFORMANCE

20 Million Charging Stations

Worldwide Expected in 2025

(UBS)



Fast Charging Expectations:

CCS **450 kW**

GB/T **900 kW**

Heavy Duty EVs **1.5 MW**

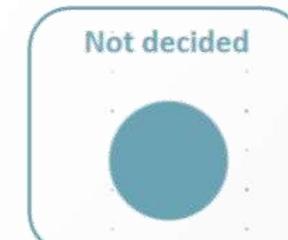
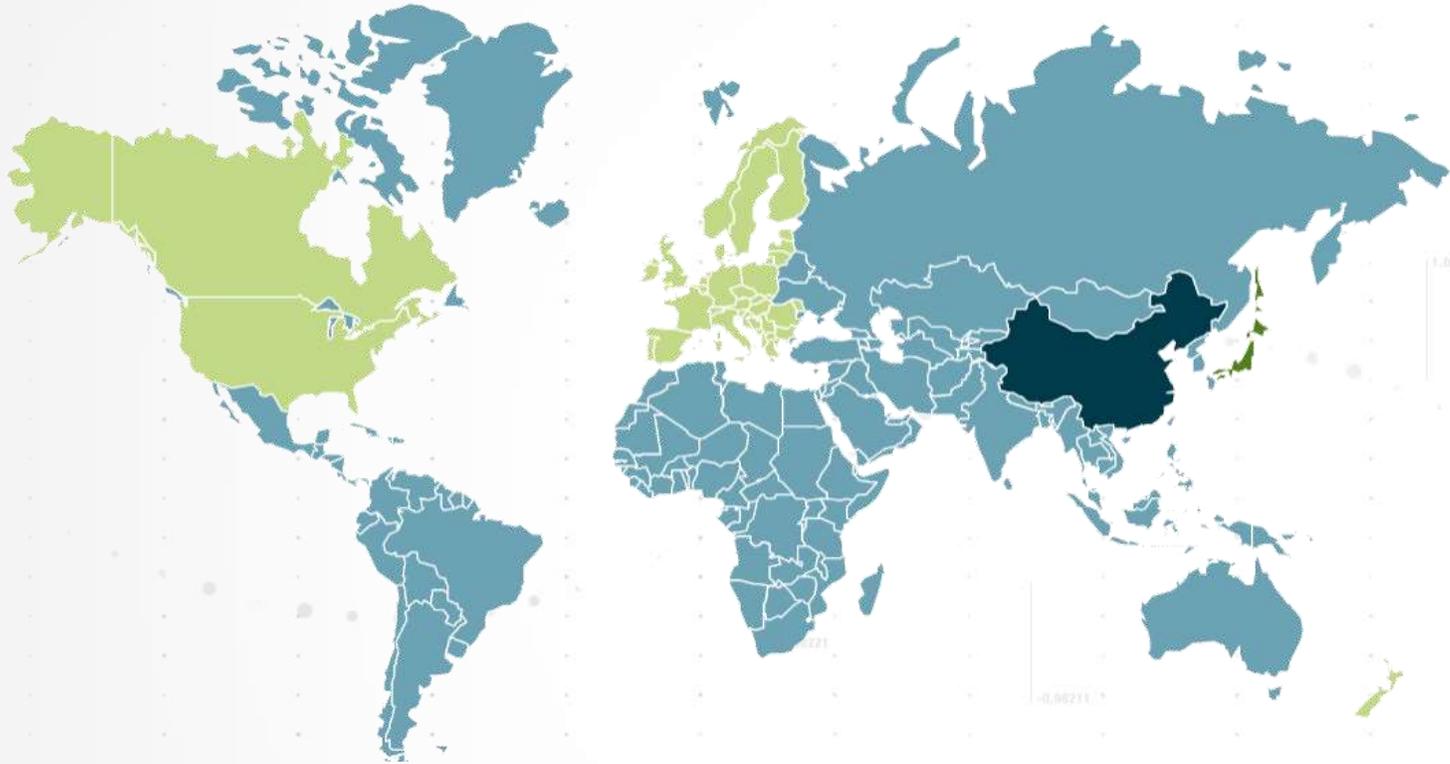
(CharIN, CHAdeMO Association)

Harmonization of Charging Standards:

Preferable: One worldwide standard

BUT: **Different economical and political interests will stop the harmonization of one worldwide standard**

Different Charging Standards Worldwide



MARKET CHALLENGE

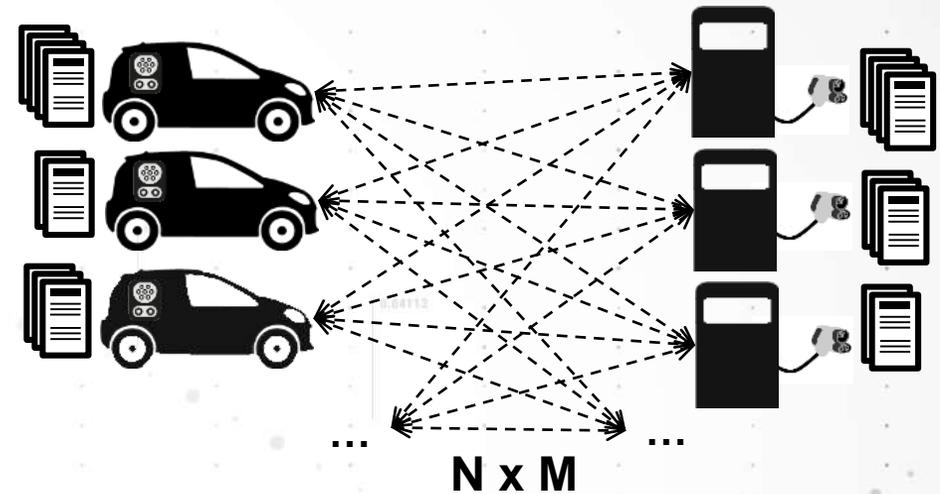
- OEMs want to sell EVs worldwide
- All the different standards need to be fulfilled

Source: CharIN

Keysight Enables Automated Interoperability Testing

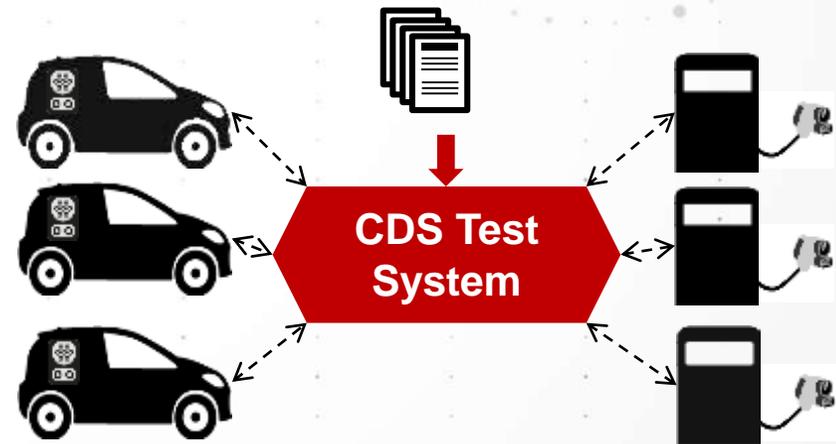
MANUAL TESTING

- Implementation vs. Implementation (good case only)
- Not feasible for growing market



AUTOMATED TESTING

- Test cases vs. Implementation (good AND error cases)
- Scalable for growing market

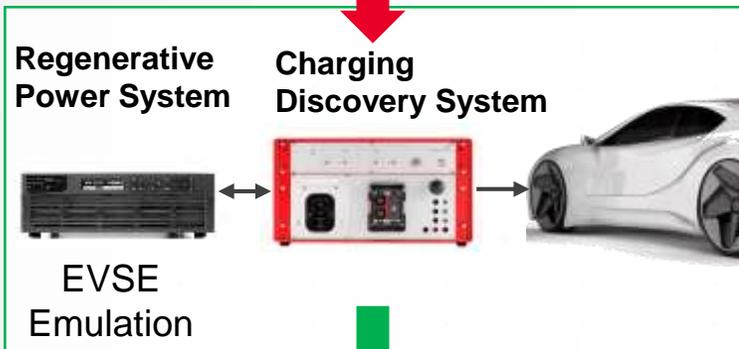


Keysight Enables Effective Charging Interface Testing

EV Test

CHALLENGE

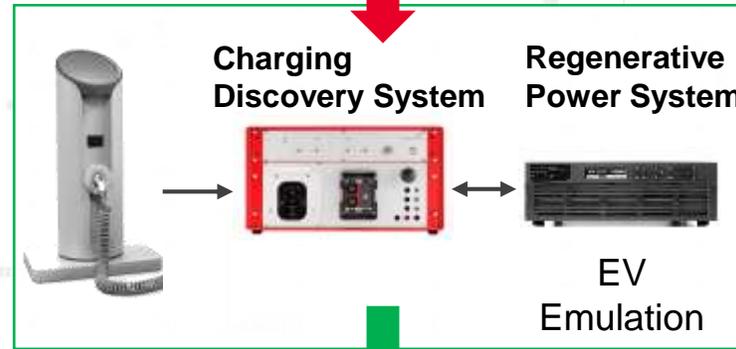
EVSE needs to be emulated according to all worldwide standards and grids



EVSE Test

CHALLENGE

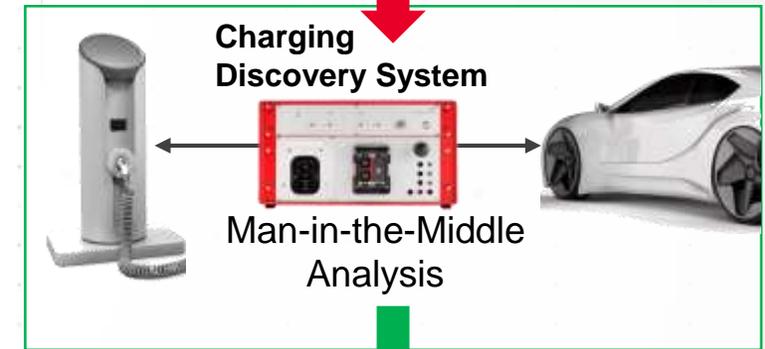
Different EVs need to be emulated with different worldwide standards



Man-in-the-Middle Test

CHALLENGE

EV and EVSE need to be interoperable according to the same, worldwide standards

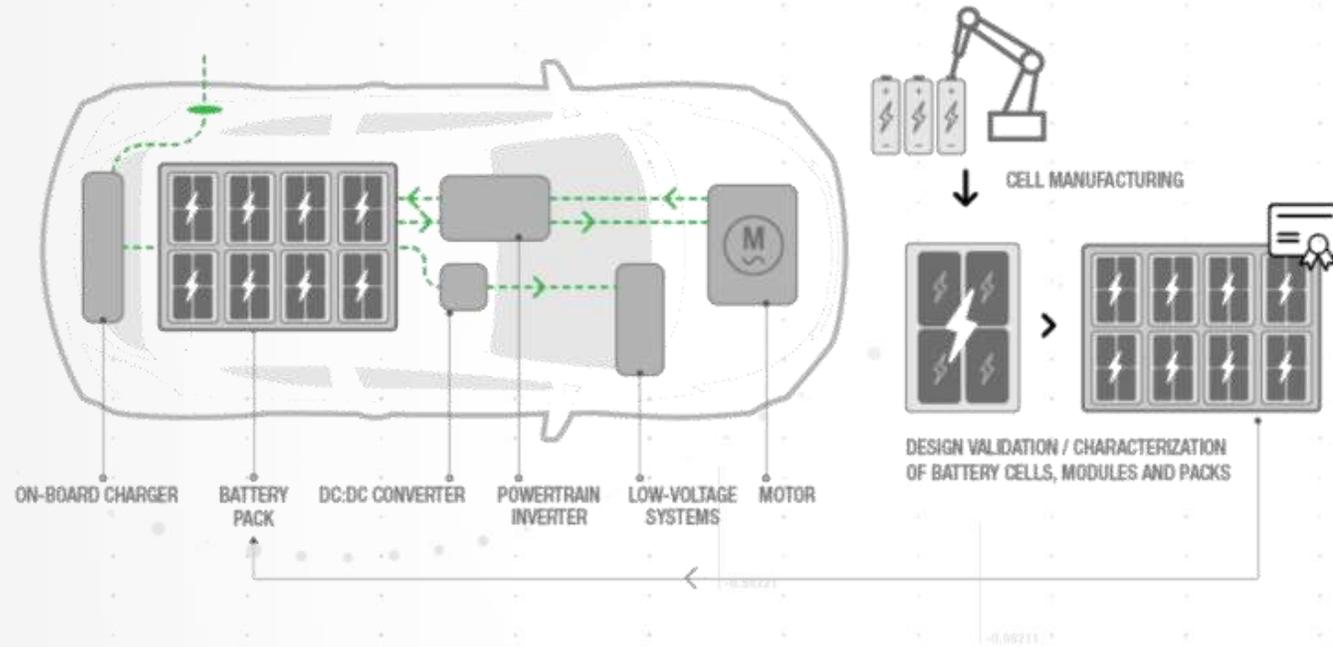


BENEFITS

- Fully integrated test solution allowing automation of all conformance test cases
 - Easy to use, state-of-the-art Software
- Ensures faster time to market

Electric Vehicles Drive Technology Investments

CELL/BATTERY DESIGN VALIDATION: PERFORMANCE, RELIABILITY, AND FAST TTM



- 75% Reduction in Battery Cost
- 75% Increase in Battery Capacity
- 35% Reduction in Battery Size and Weight by 2022 (NREL)

- Reduced Vehicle Platform Longevity
- Increase in Regulations
- Consumer Preferences are becoming more Fractionalized
- = Shorter Product Development Cycles (Center for Automotive Research)

Comprehensive Battery Test Solutions Are Needed

MARKET CHALLENGE

- Bring more EV models to market quickly,
- Reduce costs and extend the range of the EV



Need to create a lab that allows:

- Cell chemistry research and development
- Validation and functional tests of battery cells, modules and packs incl. Battery Management System (BMS)

AND is cost effective!

Challenges In Battery Testing

Task Management

Testing Capacities

Resource Management

Big Data Management

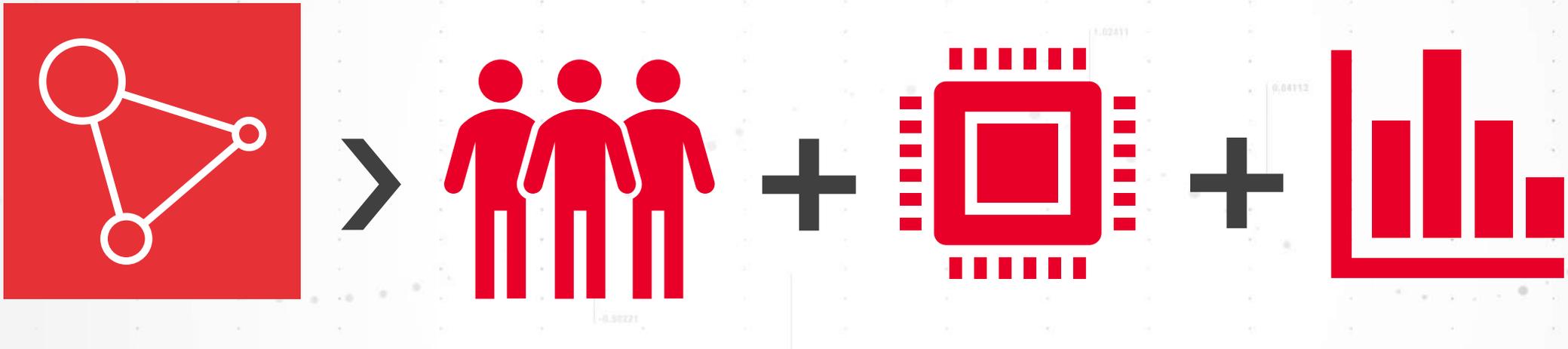
Test Efficiency

Increased Test Automation



Challenges In Design Validation Workflow Management

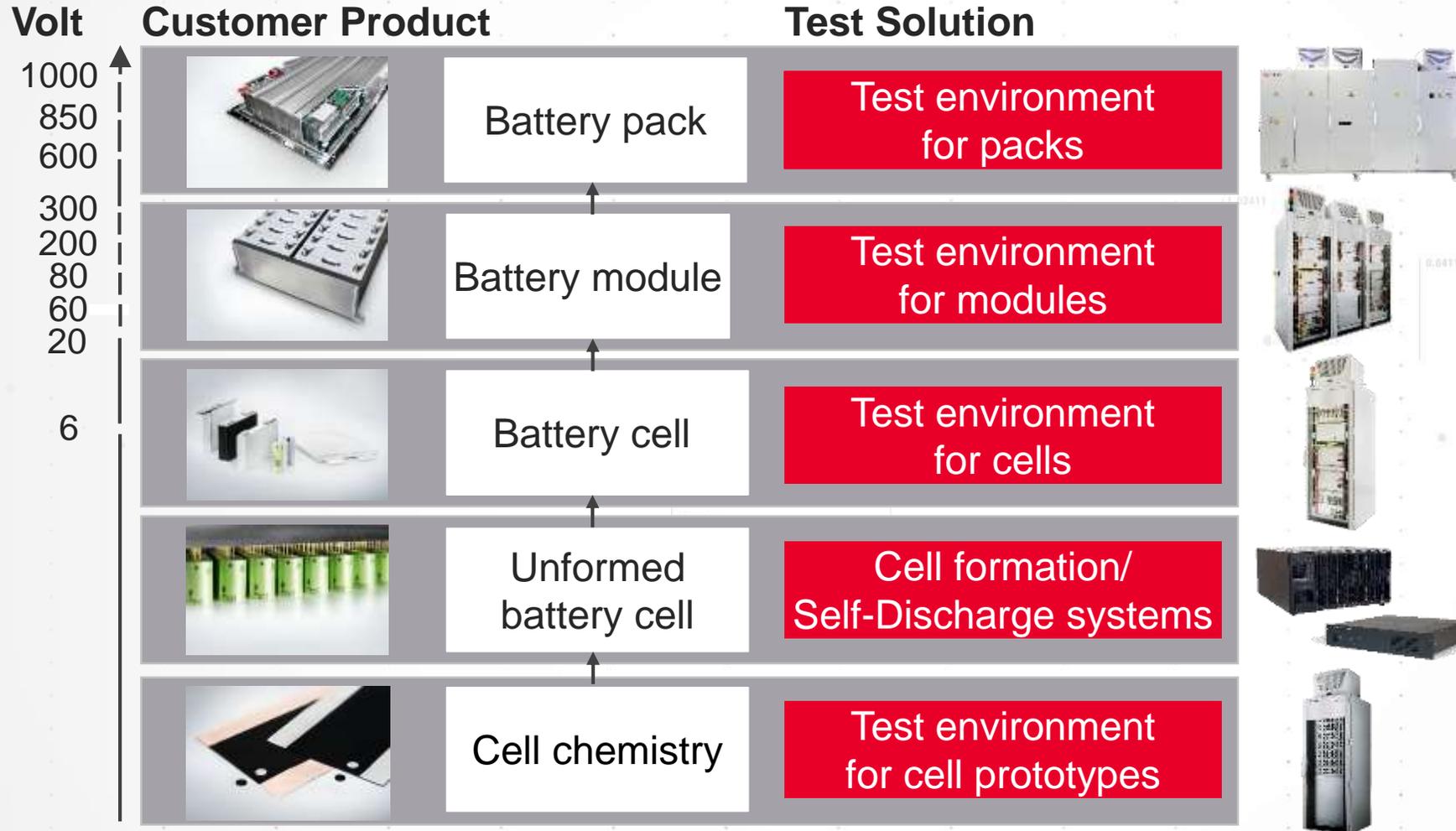
A large lab has many challenges. In general, it will require the management of **people**, **hardware** and **information**.



BENEFITS

- Workflow management and effective handling of all resources (Lab Operations for Automotive Battery Test)
 - Ensures high utilization of the laboratory
- Comprehensive testing with one state-of-the-art battery test operating software (ESD)
 - Ensures high quality cells and batteries

Battery Test Solutions From Cell Chemistry To Packs



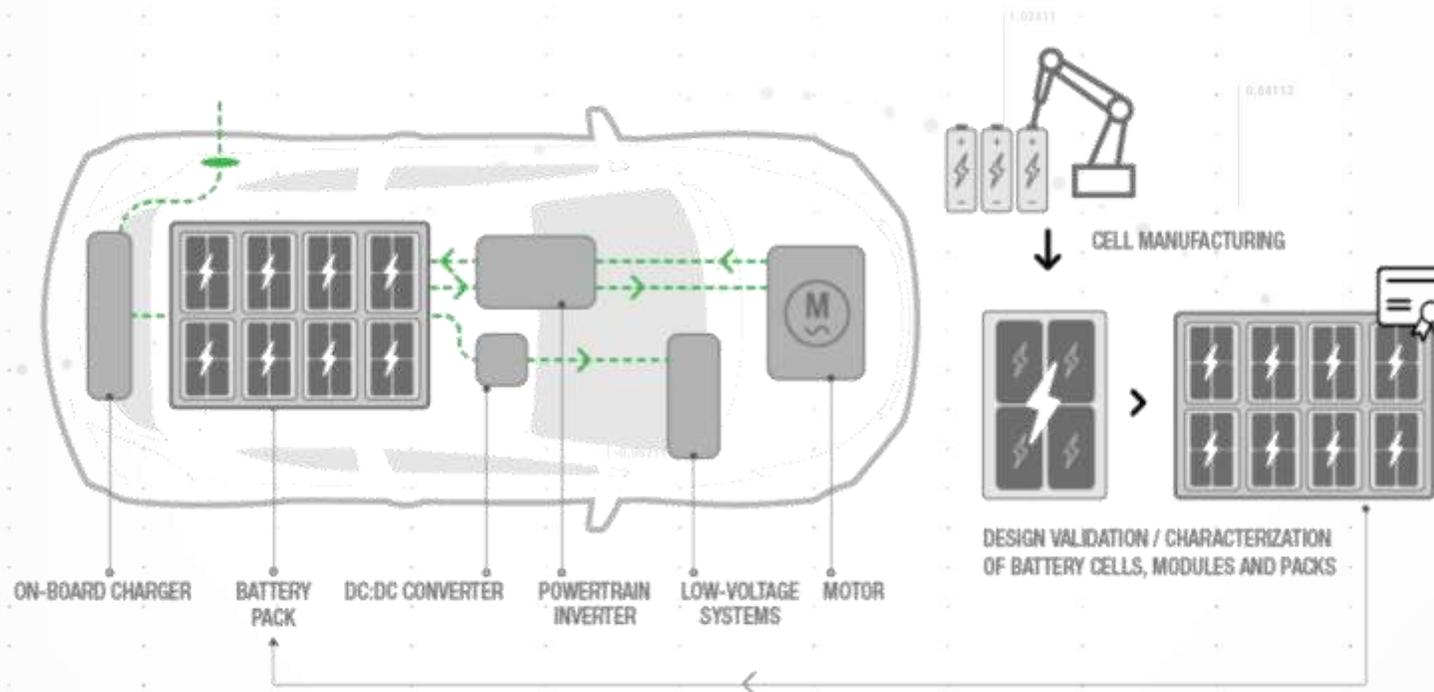
BENEFITS

- Entire process chain of battery test can be covered
- One operating software for all applications

Electric Vehicles Drive Technology Investments

CELL MANUFACTURING: CELL COST AND CELL AVAILABILITY ARE CRITICAL

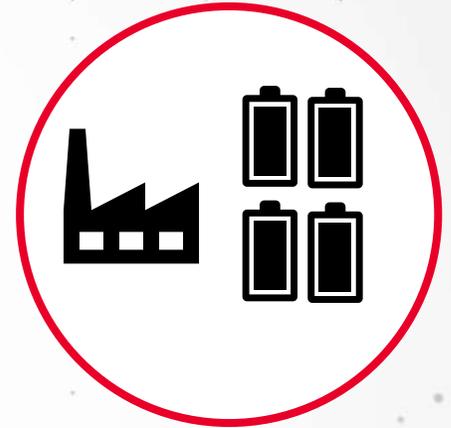
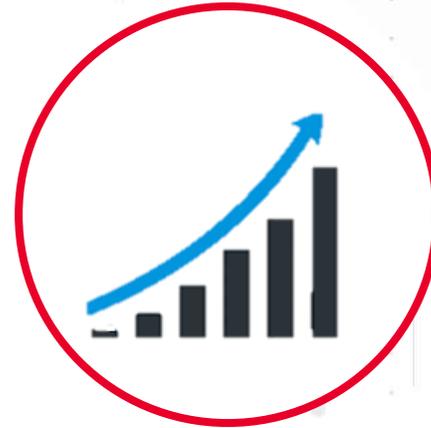
Annual **demand for cell** predicted to **increase**
from **120 GWh** in 2017 to **1000 GWh** in 2030



\$70/KWh Lithium-ion **battery pack prices** by 2030

Cells Are Critical To EV Adoption

OEMs INVESTING \$300B TO BRING EV TO MAINSTREAM



EV User Experience must be similar to ICE

- Cost too high
Must reduce cell cost
- Range too low
Must improve cells
- Charge time too long
Must improve cells, converters, chargers

Cost of cells must come down

- ICE: \$ 80/kWh equivalent
EV: \$150/kWh ← *Too high*
- 2018 Cell Manufacturers:
 - Revenue= \$32B
 - Profit = 0%

Supply of cells must meet demand

- EV demand explodes
2017: 120 GWh
2030: 1000 GWh
- > 30% CAGR
- Need more Gigafactories

Supply of cells must be assured

- OEMs want cell factories near EV factories
- New entrants to cell mfg
- Example: Europe to add 70 GWh by 2025

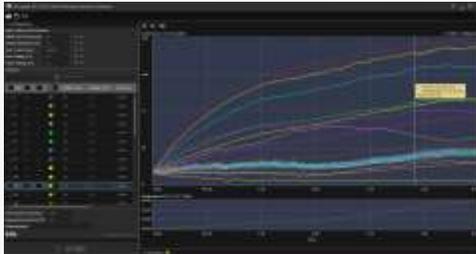
New materials - Better cells - Lower mfg cost - New factories - Right location

Accelerating Critical Improvements In Cell Manufacturing

LOWER CELL COST, INCREASE MFG CAPACITY

CHALLENGE
Decrease Cell Cost

Cell Formation & Finishing



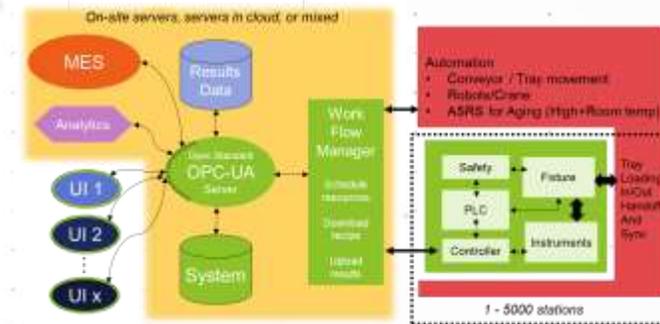
Reduce formation/finishing time (22% mfg cost) from days to hours
 Reduce power consumption (5% mfg cost) via regeneration
 Reduce \$M's of WIP
 Industry 4.0 Technologies – Lower Opex

BENEFITS

- Lower cell mfg cost
- Reduced WIP Inventory
- Improved ROA

CHALLENGE
Adequate Cell Mfg Capacity

Factories of the Future



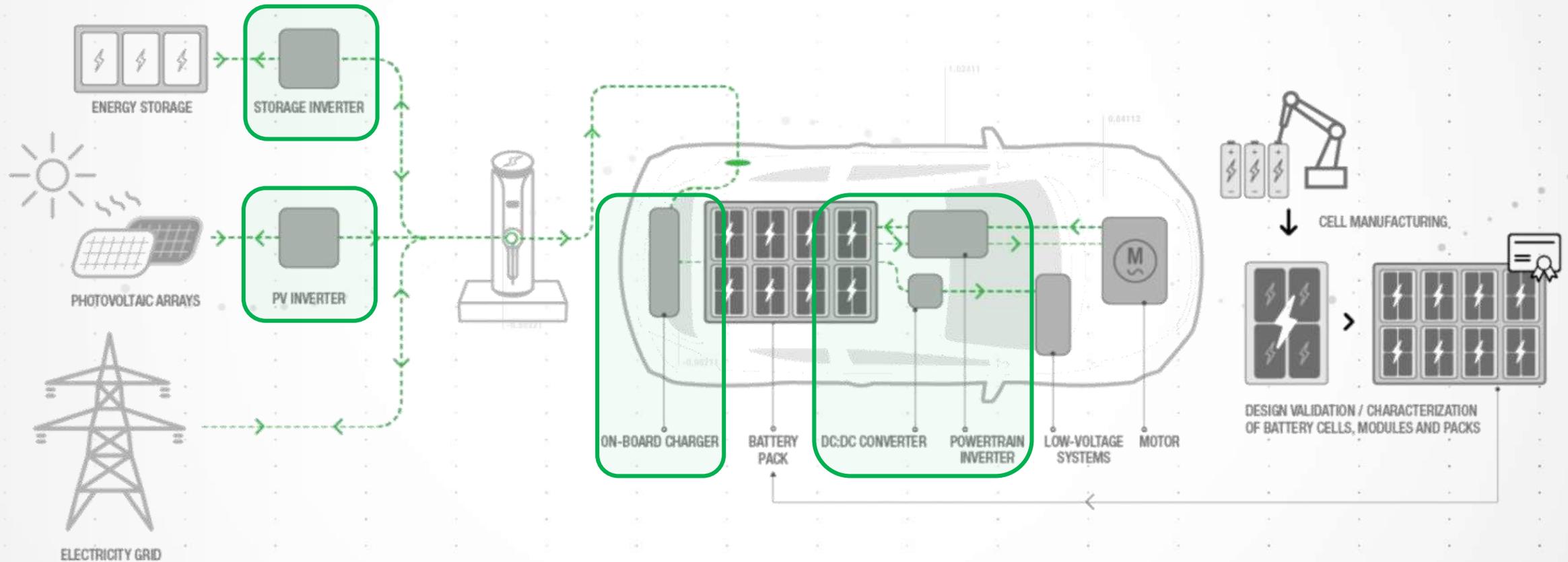
Many new suppliers – Requires scalable Mfg Test:
 R&D/Pilot lines/GFs – Stations to Fully Automated Mfg
 Mass volumes requires Big Data Mgt

BENEFITS

- Integrated Formation/Finishing/FA for Better Mfg Productivity
- Improved Process Insight & Control

The Electrification Of The Vehicle

WIDE BANDGAP DEVICES - HIGHER EFFICIENCY, LIGHTER WEIGHT, LOWER COST

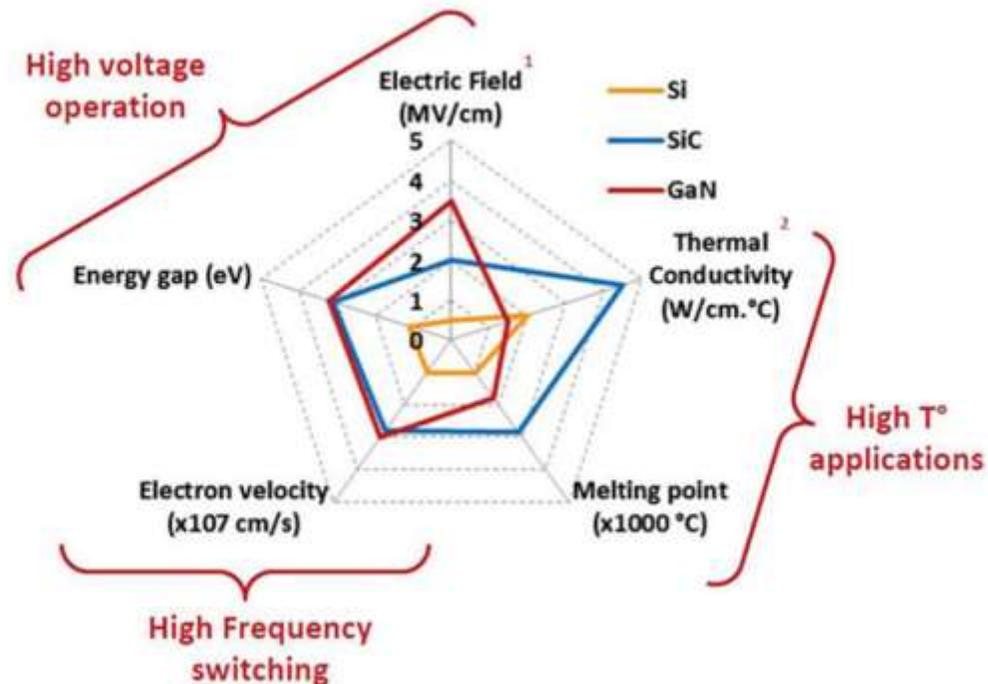


Market Needs Drive New Power Semiconductor Technology

WIDE BANDGAP DEVICES (WBG) – SILICON CARBIDE (SiC) & GALLIUM NITRIDE (GaN)

Gallium Nitride (GaN) advantages over Si

- Very fast switching frequency
- Compactness and weight reduction
- 3X higher bandgap of Si
- Reduction of conduction and switching loss
- Low $R_{DS(on)}$



Silicon Carbide (SiC) advantages over Si

- High Temperature Operation
- 3X thermal conductivity of Si
- 3X higher bandgap of Si
- 10X higher breakdown field
- Up to 1000X lower $R_{DS(on)}$ (conductive loss)

MARKET CHALLENGE

- Lighter Weight Vehicles leads to Extended Vehicle Range
- Reduce Costs

Barriers To Wide BandGap (WBG)

DISRUPTIVE CHANGE FOR POWER CONVERTER DESIGNERS

WBG Market Challenge: Reliability in mission critical applications



Established Standards Committee for WBG devices September 2017



JC-70
Wide Bandgap Power Electronic Conversion Semiconductors

JC-70.1
Subcommittee GaN
Power Electronic Conversion Semiconductor Standards

JC-70.2
Subcommittee SiC
Power Electronic Conversion Semiconductor Standards

Power Semiconductor Characterization Solutions

GAIN INSIGHT INTO YOUR POWER SEMICONDUCTOR CHARACTERISTICS

Static Characterization



CHALLENGE
Characterizing new, less-reliable IGBT, SiC and GaN power semiconductors

Dynamic Characterization



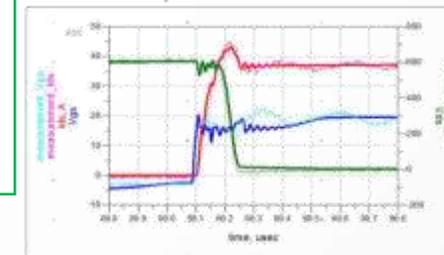
B1505/6A Power Device Analyzer

- Wide operation range up to 3 kV/1500 A
- Fully automated fast thermal test from -50°C to +250°C
- Automatic power device (semiconductor and component) datasheet creation
- Auto record function to prevent data loss
- Power Semiconductor characteristics – Ron, BV, Leakage, Vth, Vsat, CV, Qg, etc.

BENEFITS

Reduce design time with fewer prototypes
→ Faster TTM & Reduced Cost

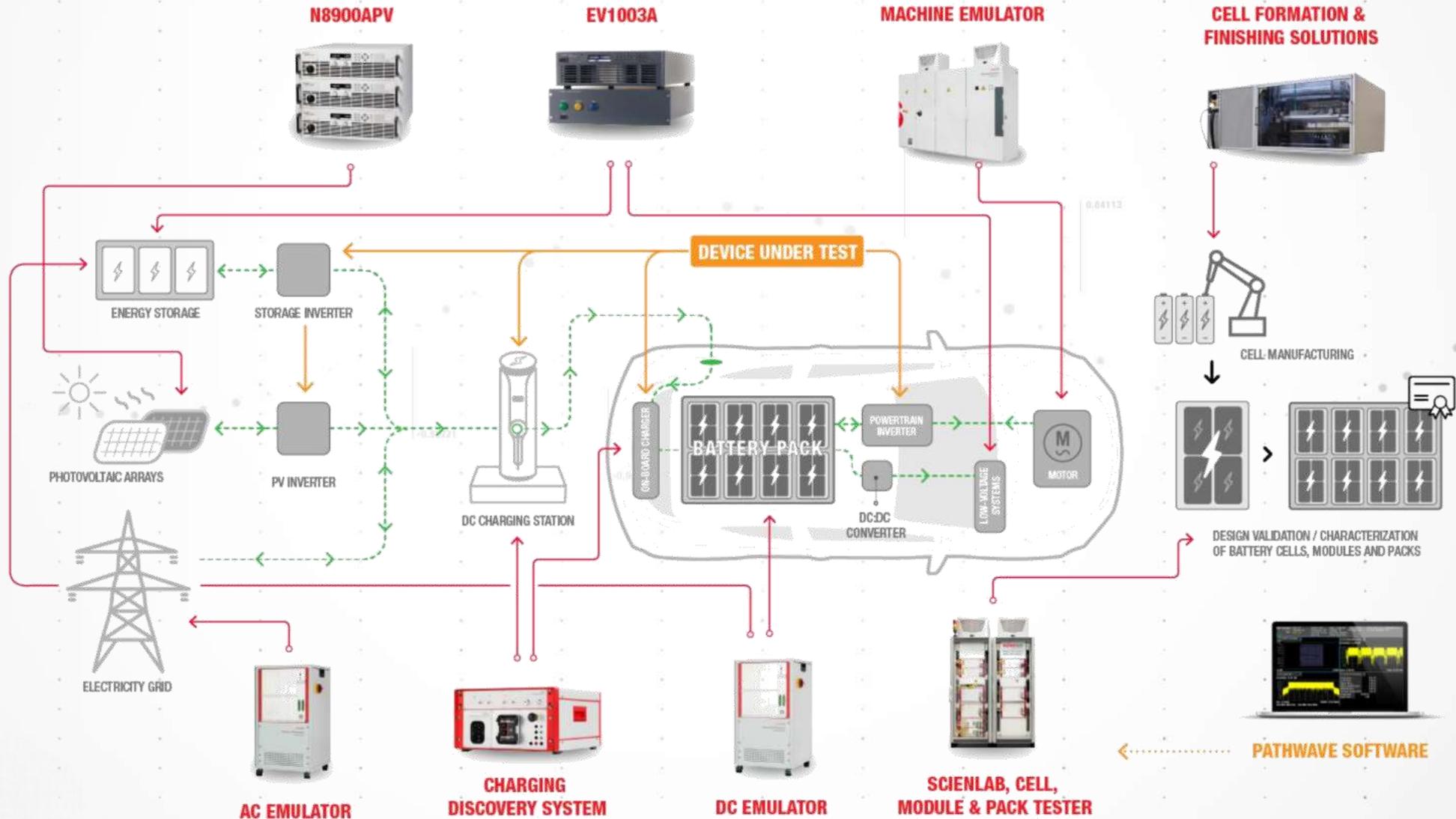
PD1000A Dynamic Power Device Analyzer



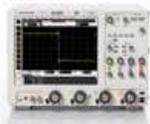
- Double Pulse Test
- Short Circuit Test
- Avalanche Test
- Safe Operating Area (SOA)

The Electrification Of The Vehicle

KEYSIGHT SOLUTIONS



Our Engagement Model Is Partnership



Workflow

Maximum Contribution

Help customers optimize workflow processes with Keysight tools. Become part of automation flow

Solutions

Higher Value

Complete end-to-end answers to a customer problem
Software , Fixturing, HW, Expertise

Applications

One Supplier

Multiple Keysight products based on fit to specific customer applications. One Stop Shopping Value

Products

Single Product

Single products based on best-in-class attributes.



Summary

Fundamental disruptive innovations in automotive will create a new mobility ecosystem

It is our chance to create together a connected and better world

Let's partner to master the technological challenges and bring your innovations to market first

Automotive & Energy Track Demos

SEE AND HEAR THE LATEST AND GREATEST FROM INDUSTRY EXPERTS

E-Mobility

Scienlab EV Test Solutions
Battery Test Systems
HEV/EV Power Converter

Autonomous Driving

Radar Signal Analysis
Radar Signal Generation
Radar Target Simulator
SystemVue Radar Simulation Library

Automotive Ethernet

Transceiver (Tx) Compliance
Receiver (Rx) Compliance
Link Segment (Lx) Solution
Ixia Level 2-7 Network and Application Testing

V2X Connected Car

Dedicated Short-Range Communications (DSRC)
5G/Cellular V2X (C-V2X)
e-Call

Automotive & Energy Resources

FIND THE LATEST AND GREATEST FROM INDUSTRY EXPERTS

Automotive & Energy Solutions

Realize Your Vision Of Mobility

[Keysight.com/find/automotive](https://www.keysight.com/find/automotive)



E-Mobility

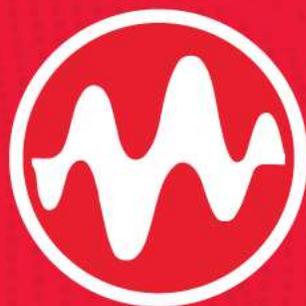
[Keysight.com/find/e-mobility](https://www.keysight.com/find/e-mobility)

Autonomous Driving

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