Overview of NIST Workshop on
Power Conditioning System Architectures for Plugin-Vehicle Fleets as Grid Storage

(Held at The Pentagon on June 13, 2011)

Presented by Allen Hefner (NIST)

http://www.nist.gov/pml/high_megawatt/

Questions Addressed by Workshop

1) US Policy and Programs for Electric Transportation

2) Use of PEV as Grid Storage

Panel A: What are existing ancillary service markets where a Plugin Electric/Hybrid-Electronic Vehicle (PEV) Fleet might participate?

Panel B: What additional grid storage requirements and opportunities might emerge that could utilize a PEV Fleet?

Panel C: How might a PEV Fleet aid in integration of distributed variable renewable generators?
How might a PEV Fleet aid in integration of resilient micro-grids?

Panel D: How might use of PEV battery as grid storage impact on battery life?

3) PCS Architectures for PEV as Storage

Panel E: What PEV charging and bi-directional charging units are available today?
How might onboard vehicle propulsion inverters and converters be utilized for PEV grid interconnection?

Panel F: How might large grid inverters be used to integrate multiple vehicles and other generator/storage devices?
How might DC circuits and DC micro-grids be utilized within a PEV Fleet Power Conditioning System (PCS) architecture?

4) Transition to PEV Fleet as Storage

Panel G: In addition to DOD what other potential large PEV Fleets as storage might emerge?

Breakout: How might the value proposition of different PEV Fleet PCS approaches be categorized by vehicle type, fleet usage type, and local grid type?
What are PCS gaps and next steps required to enable Vehicle Fleet as storage?

1) Policy and Programs for Electric Transportation

- US federal policy is supporting the electrification of the US vehicle fleet to accomplish the objectives:
  - reducing fossil fuel consumption,
  - reducing air pollution (including CO_2),
  - and increased use of alternate fuel vehicles.
- DOD is considering an optimal strategy to maximize use of Electric Vehicles in DOD's non-tactical ground fleet, while minimizing lifecycle investment.
- Achieve lifecycle cost parity (or better) between EV's and comparable ICE vehicles.
- Begin large-scale integration of PEV's within FY2012 to last over a period of 3-5 years

Workshop Objectives

- Focus on PEV Fleet deployment options for 1-5 years.
- Evaluate options to increase value proposition for V2G:
  - identify inverter and storage functions that provide value
  - consider impact of these functions on battery/inverter life
  - identify PCS architectures that might be low cost and suitable for near term deployment including grid integration requirements
- Define Fleet types (public and private) that might participate.
- For each Storage/Inverter function, PCS architecture, and PEV Fleet type what are:
  - advantages and disadvantages
  - technology and utility readiness for 1-5 year timeframe
  - appropriate approaches for different fleet types.

NIST
National Institute of Standards and Technology

2) Use of PEV as Grid Storage

Panel A: What are existing ancillary service markets where a Plugin Electric/Hybrid-Electronic Vehicle (PEV) Fleet might participate?

Panel B: What additional grid storage requirements and opportunities might emerge that could utilize a PEV Fleet?

Panel C: How might a PEV Fleet aid in integration of distributed variable renewable generators?

How might a PEV Fleet aid in integration of resilient micro-grids?

Panel D: How might use of PEV battery as grid storage impact on battery life?

Use of PEV as Grid Storage (Panel A and B)

- Economic drivers for storage include:
  - supplying cost-effective ancillary services,
  - peak load shaving/leveling,
  - more efficient energy arbitrage,
  - premium power for islanding,
  - and smoothing rapid ramp rates of solar, wind, and large loads.
- Several demonstration projects have shown that it is technically feasible to provide grid storage functions with PEVs
- Currently, battery and vehicle manufacturers believe fast charging and deep Depth-of-Discharge cycles will negatively impact the life of batteries:
  - Value proposition for PEV depends on vehicle transportation and grid storage usage and is uncertain for typical consumer.
  - Fleet Vehicles with well defined use conditions present a unique opportunity to assure value proposition from V2G

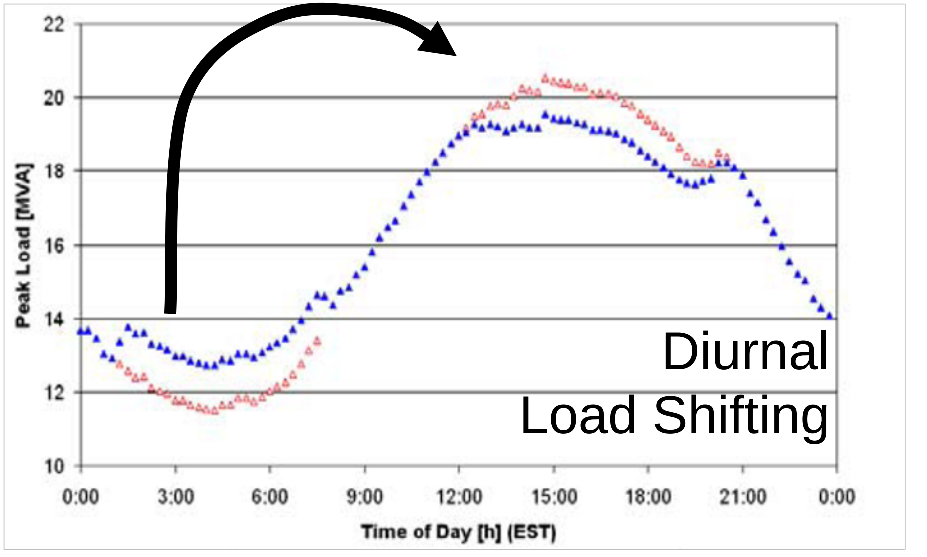
NIST
National Institute of Standards and Technology

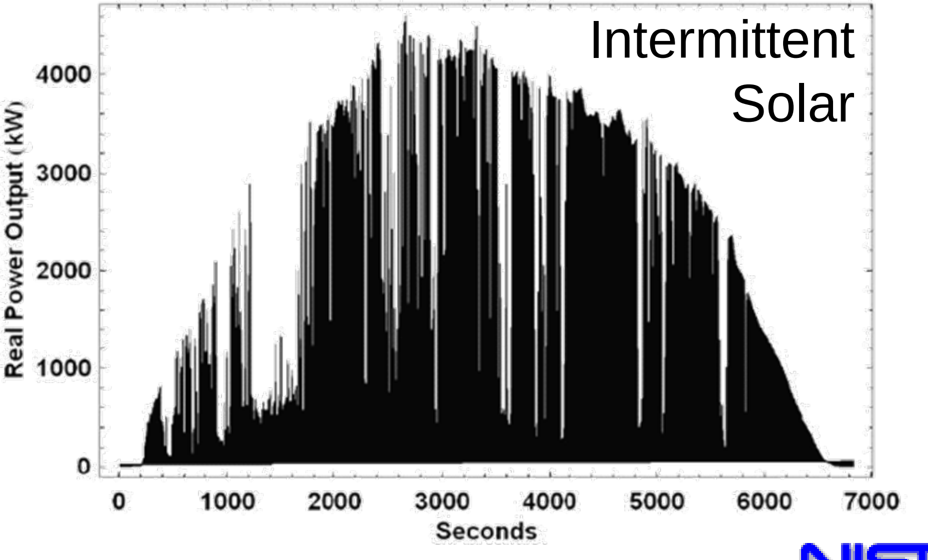
Energy Storage Applications

- **Today's Grid** connects electricity
  WHERE it is needed,
  Storage adds electricity
  WHEN it is needed

- **New Needs**
  – Renewable Generation and Electric Vehicle Integration
  – Peak Demand Shaping
  – Power Quality with Smart Grid / Load Management

- **Timing Matters**
  1 cycle to 1 minute:
  inertia, spinning reserve
  10 minutes to hours:
  ramping, diurnal storage





courtesy: Mark Johnson (ARPA-E)

NIST National Institute of Standards and Technology

Energy Storage Technologies

Energy ($/Whr)

Power ($/W)

- Pumped Hydro
- Compressed Air Energy Storage (CAES)
- Batteries
  - NaS
  - Flow Batteries
  - Lead Acid, Lead Carbon
  - Lithium Ion
  - NiMH
  - NiCad
- Flywheels
- Electrochemical Capacitors

Taum Sauk
400 MW

NaS
2 MW

Flywheels
1 – 20 MW

courtesy: Imre Gyuk (DOE OE)

Use of PEV as Grid Storage (Panel C and D)

- Grid storage/inverter functions can have positive and/or negative affects on local and region grids; e.g., participation in regional markets can impact local distribution system power quality.
- Distributed Energy Resources (DER) including generators and storage devices must comply with interconnection regulations of the local Public Utility Commission (in most states this is based on IEEE 1547 with local exceptions).
- DER installations must also meet the local legal requirements for compliance with the NFPA, National Electrical Code including UL 1741 conformity testing of installed devices.
- PhotoVoltaic (PV) Solar generators have spearheaded the development and utility acceptance of grid inverter functions.
- The Smart Grid Interoperability Panel - Priority Action Plan 7, and the EPRI PV-Storage Communication Project defined requirements for storage functions in IEEE 1547.8 and IEC 61850-7-420.

PAP 7: Storage-DER Smart Grid Standards

Task 0: Scoping Document

Prioritized timeline for ES-DER standards

Task 1: Use Cases, *EPRI PV-ES Inverter

Define requirements for different scenarios

Task 2: IEEE 1547.4 for island applications and IEEE 1547.6 for secondary networks

Task 3: Unified interconnection method with multifunctional operational interface for range of storage and generation/storage.

IEEE 1547.8
- (a) Operational interface
- (b) Storage without gen
- (c) PV with storage
- (d) Wind with storage
- (e) PEV as storage

Info exchanges

MIC

PAPs

Task 4: Develop and Harmonize Object Models

IEC 61850-7-420: Expanded to include
- Multifunctional ES-DER operational interface
- Harmonized with CIM & MultiSpeak
- Map to MMS, DNP3, web services, & SEP 2

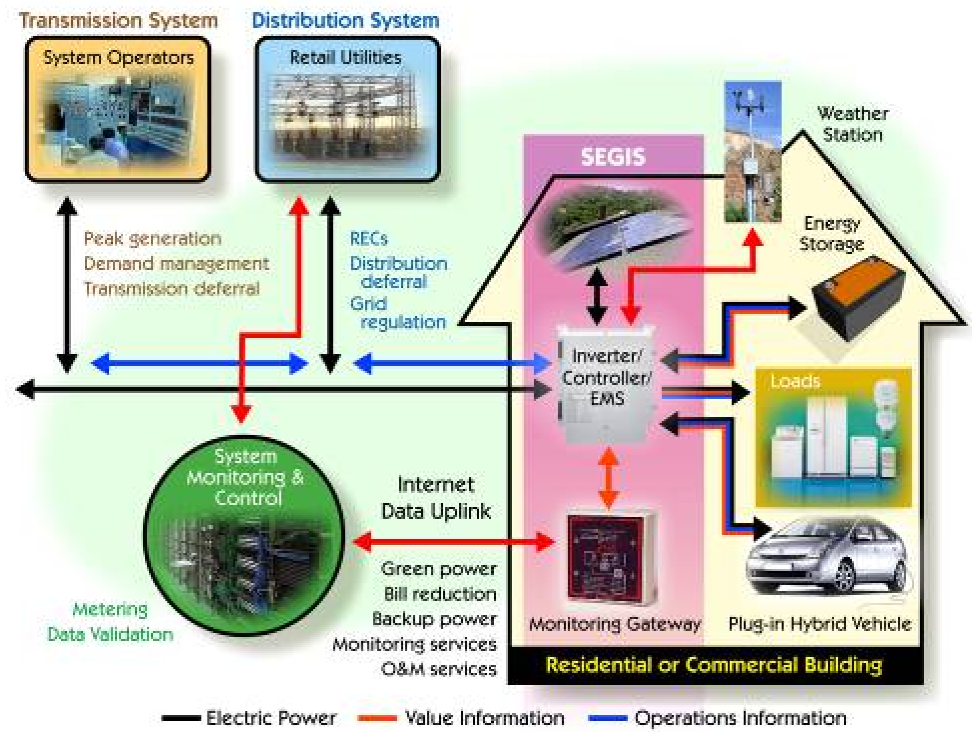
Task 5: Test, Safe and Reliable Implementation

UL 1741, **NEC**-NFPA70, SAE, CSA and IEC

PV-Solar Spearheading Grid Integration of Inverters

DOE SunShot Initiative

- ***Solar Energy Grid Integration Systems – Advanced Concepts (SEGIS-AC)***: inverter/controllers, energy management.
- Developed more reliable inverter and controller hardware.
- Embedded voltage regulation in inverters, controllers, voltage conditioners.
- Investigated new DC power distribution architectures.



<u>**The Solar Energy Grid Integration System (SEGIS) Integrated with Advanced Distribution Systems**</u>

NIST
National Institute of Standards and Technology

3) PCS Architectures for PEV as Storage

Panel E: What PEV charging and bi-directional charging units are available today?

How might onboard vehicle propulsion inverters and converters be utilized for PEV grid interconnection?

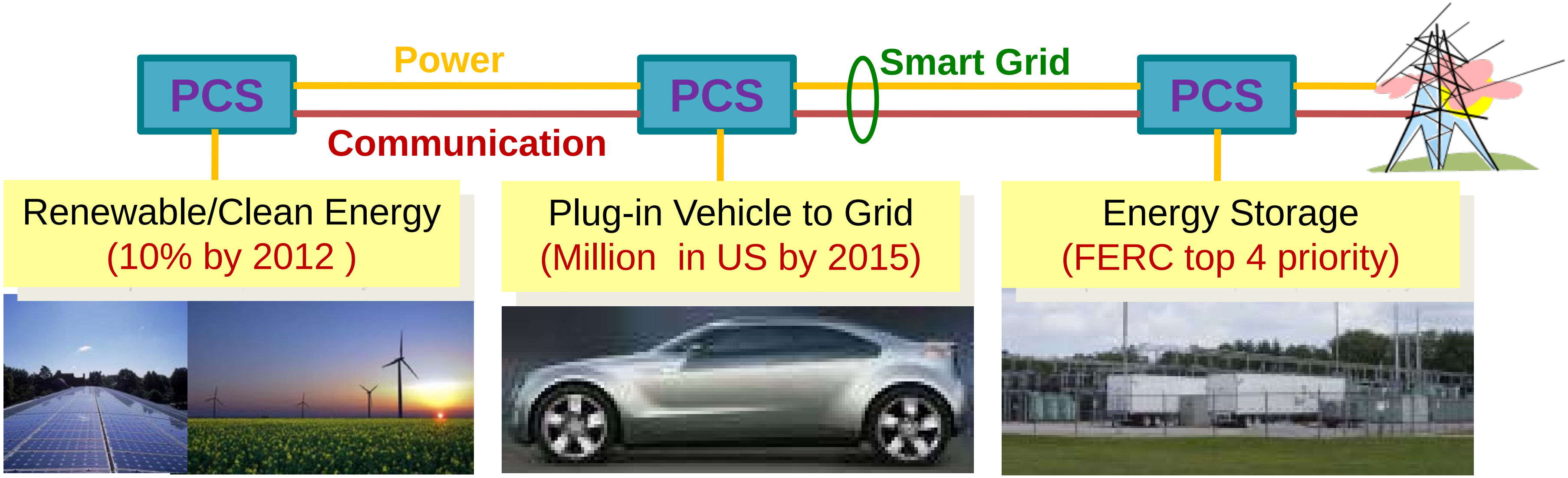
***Panel F*:** How might large grid inverters be used to integrate multiple vehicles and other generator/storage devices?

How might DC circuits and DC micro-grids be utilized within a PEV Fleet Power Conditioning System (PCS) architecture?

PCS Architectures for PEV as Storage

- Value of V2G storage/inverter functions are offset by the additional lifecycle cost of PCS and degradation of the battery.
- Bi-directional charger options include on-board or off-board, integrated with drive-train power electronics, and integration with renewable generators and stationary storage.
- PCS architectures have different cost, functionality, communication and control requirements, and ability to integrate multiple devices.
- Two-stage architectures: DC-DC converter and DC-AC inverter/ rectifier can optimize cost and enable devices to share inverter.
- Modular bi-directional DC-DC converters, are reported to be significantly cheaper than Level 3 AC chargers.
- Integrated architectures deliver power to both mobile and stationary systems to enhance operation and alleviate Solar ramp-rate induced power quality problems at the source.

High Penetration of Distributed Energy Resources

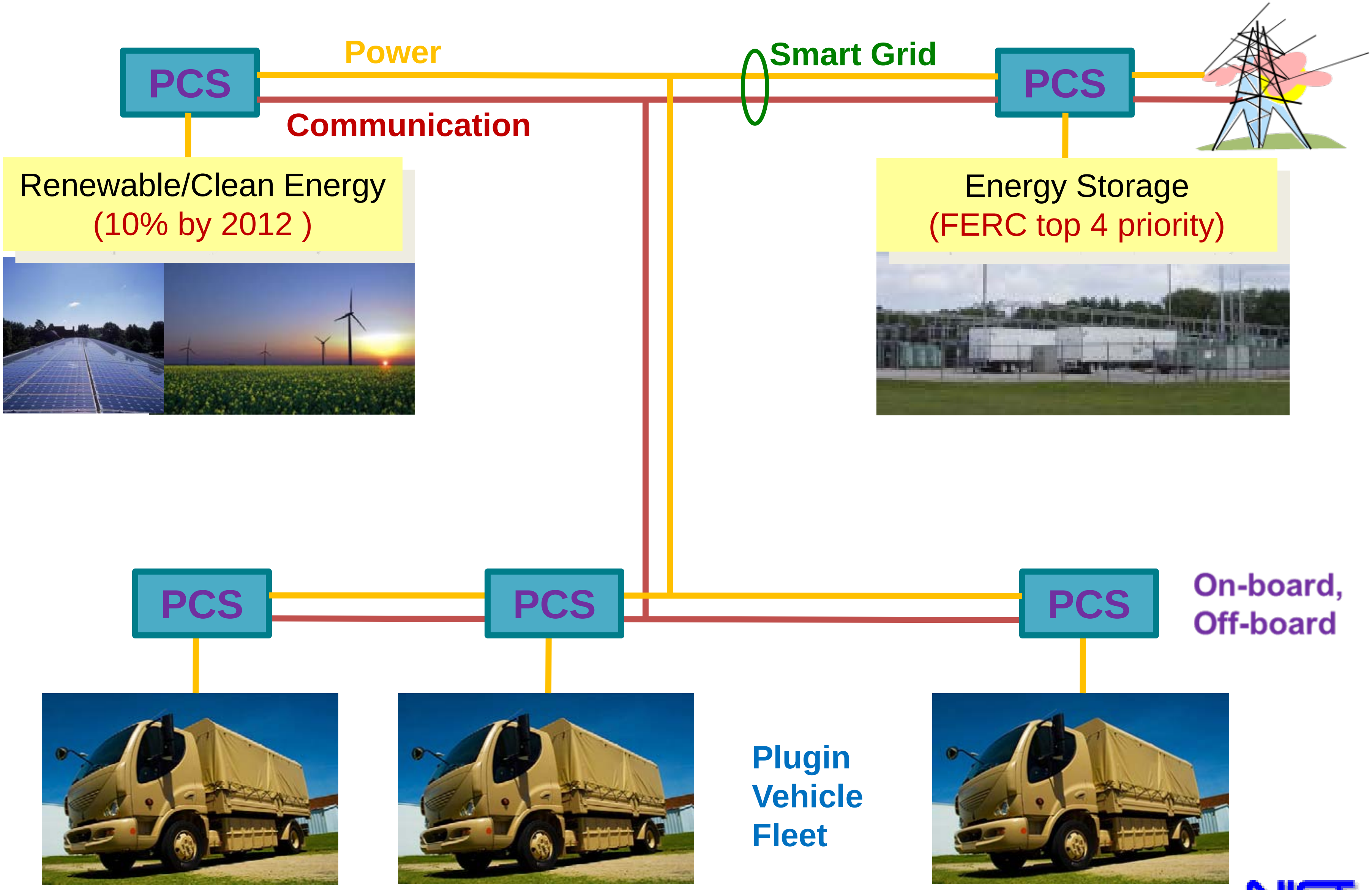


- Power Conditioning Systems (PCS) convert to/from 60 Hz AC for interconnection of renewable energy, electric storage, and PEVs

- "Smart Grid Interconnection Standards" required for devices to be utility controlled operational asset and enable high penetration:
  - **Dispatchable real and reactive power**
  - **Acceptable ramp-rates to mitigate renewable intermittency**
  - **Accommodate faults faster, without cascading area-wide events**
  - **Voltage/frequency regulation and utility controlled islanding**

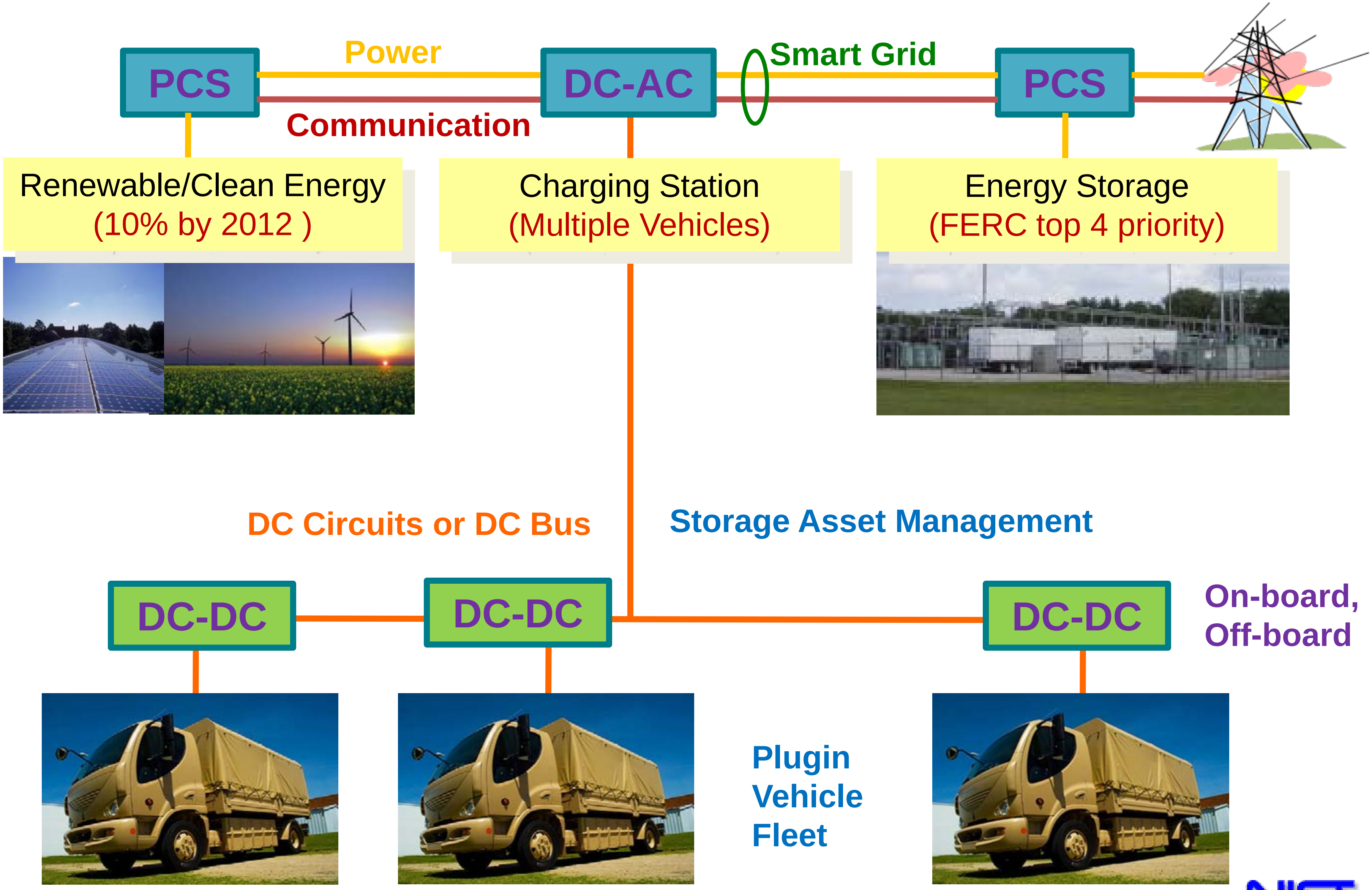
NIST
National Institute of Standards and Technology

PCS for Individual Fleet Vehicles



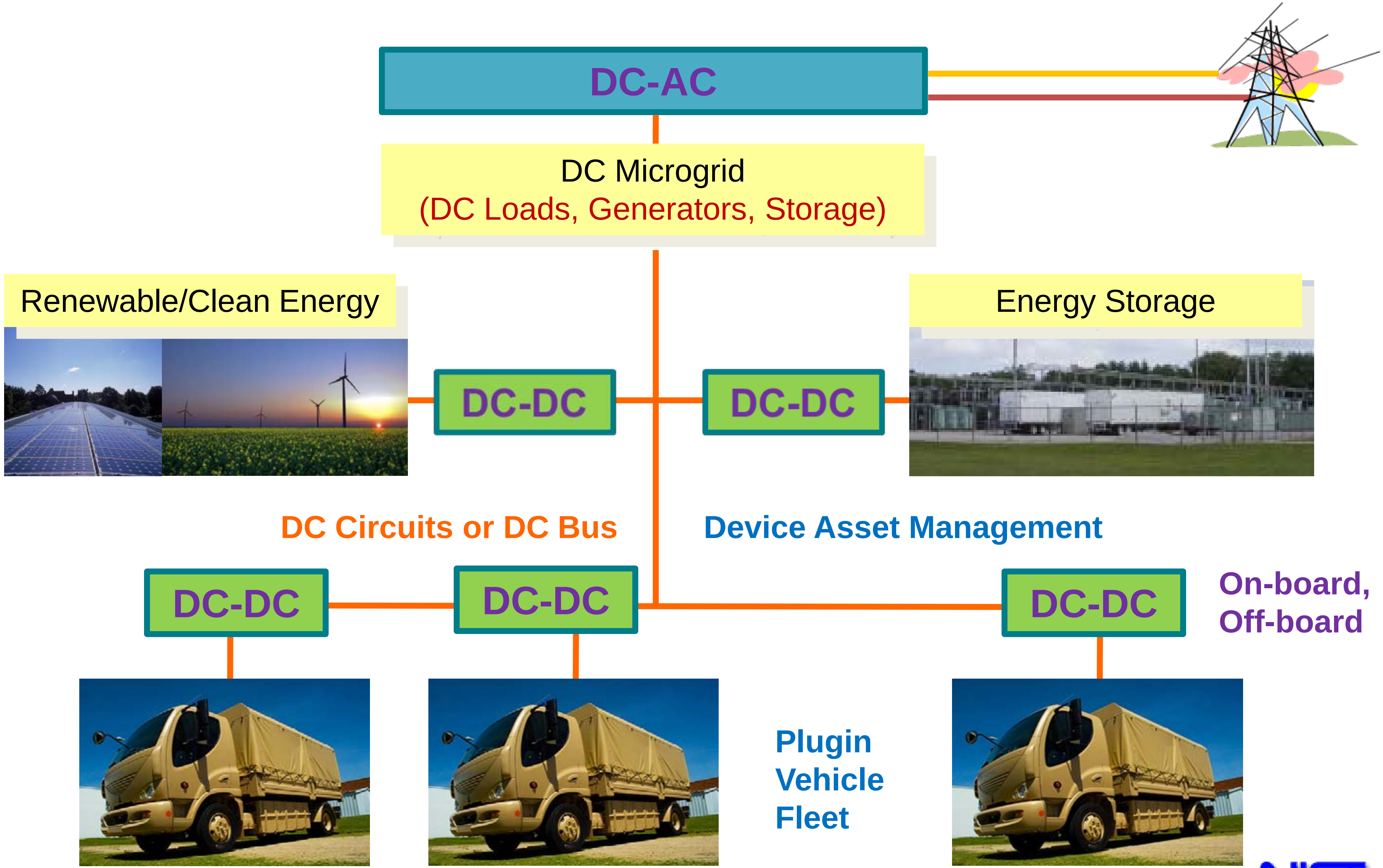
NIST
National Institute of Standards and Technology

Large Inverter with DC Circuit to Fleet PEVs



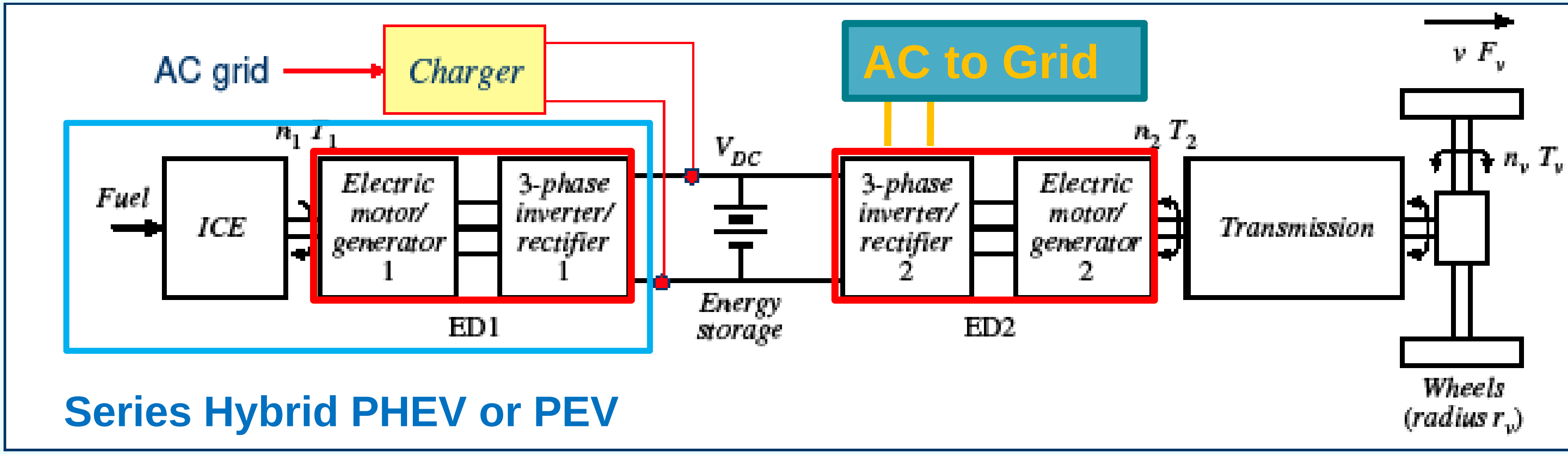
NIST
National Institute of Standards and Technology

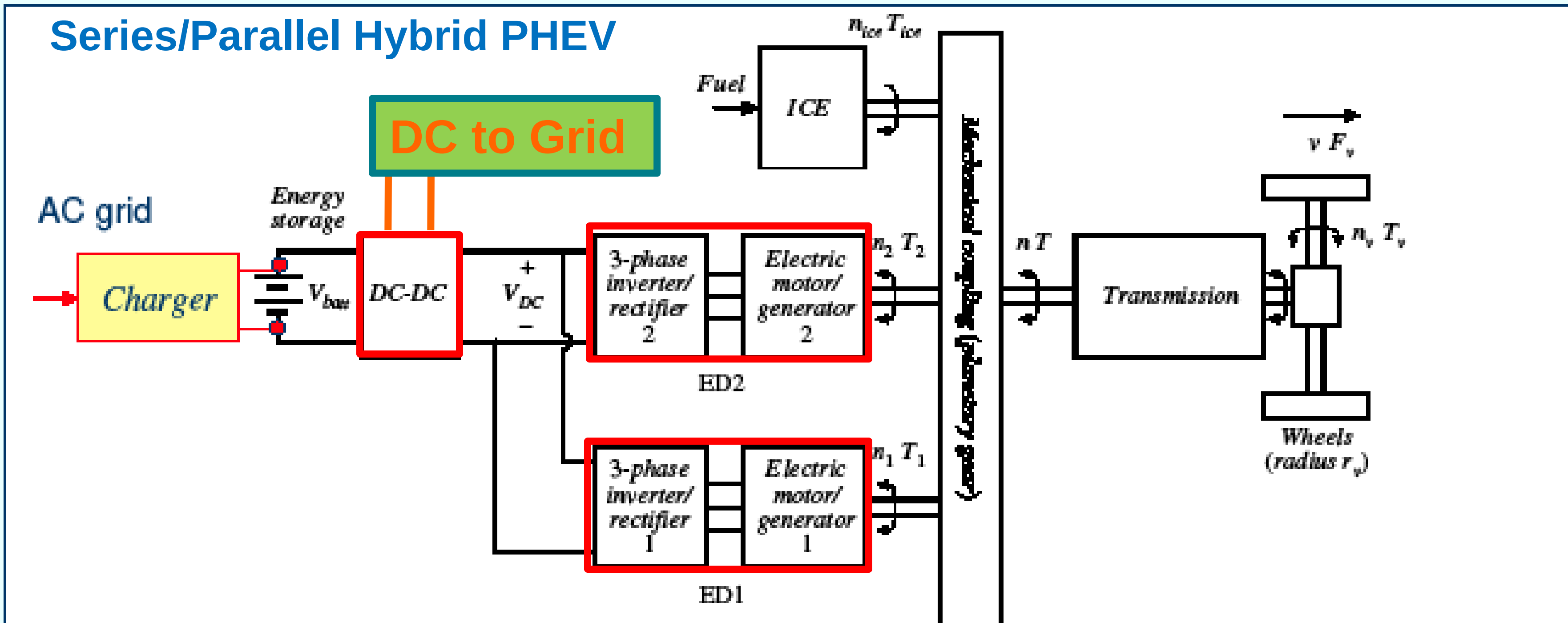
DC Microgrid with Renewable, Storage and PEVs



NIST
National Institute of
Standards and Technology

Separate vs. Merged Propulsion/Grid PCS





4) Transition to PEV Fleet as Storage

Panel G: In addition to DOD what other potential large PEV Fleets as storage might emerge?

Breakout: How might the value proposition of different PEV Fleet PCS approaches be categorized by vehicle type, fleet usage type, and local grid type?

What are PCS gaps and next steps required to enable Vehicle Fleet as storage?

DOD PEV Vehicle Fleets

- Typical vehicle usage in the US currently averages about one hour per day, leaving the other 23 hours per day potentially available for V2G applications.
- The majority of DoD trucks average about 6000 miles per year of use, compared to less than 20,000 miles per year for DOD passenger vehicles, which are both low use factors.
- Other attractive opportunities exist with vehicles and fleets that have a low service factor including delivery vans, rental car lots, used car lots, taxi fleets, bus fleets, school bus fleets etc.

V2G Opportunities

- The number of PEV vehicles and fleets are expected to increase in size as federal government energy goals are pursued.
- DoD has specific targets for reducing liquid fossil fuel (gasoline and diesel) consumption.
- Several DoD bases have specific objectives of becoming grid independent islanded operations for security purposes. In support of that objective, plans are in place to increase the amount of on-base renewable power production.
- Utilization of the power stored in the batteries of idle base vehicles could allow:
  - elimination of high-priced peak-power purchases
  - Inject relatively small amounts of stored energy into local T&D networks to smooth out grid operation
  - provide renewable ramp-rate smoothing
  - provide fast response power during transition to islanded mode during start up of diesel generators.

NIST
National Institute of Standards and Technology

V2G Issues (1 of 2)

- Who owns the batteries -- fleet owner, individual vehicle owner, leasing company, government unit (DoD), or other?
- What types are contractual options can be used to provide an economic return to battery owners for V2G functions?
- Can small sources of battery-stored electricity be aggregated into marketable bundles that can be bid for ancillary service functions and what is communication/control requirement?
- How can individual battery owners be compensated for supplying electricity?
- Will there be penalties for failure to deliver?
- Who develops the software and communication and cyber security to control and measure operation?
- How does the V2G system operate in normal operation and during the need for critical resource operation during a reliability compromise?

National Institute of Standards and Technology

V2G Issues (2 of 2)

- Lower cost, more efficient converters and inverters are being developed for this market. What is the timing of commercial availability and cost of these devices?
- When will advanced storage/inverter interconnection practices (IEEE 1547.8) and object model standards (IEC 61850-7-420 normative revision and informative document) be available?
- What is the acceptable level of power quality delivered by the V2G operator to meet distribution and transmission requirements?
- Is galvanic isolation of V2G systems required?
- Inverter systems may need to be remote upgradable to take advantages of future advanced inverter/storage functions.

DOD Base V2G Fleet Business Models

- A market exists for electricity that can be delivered to the grid from vehicle batteries for ancillary services.
- A business model needs to be developed to accrue benefit for providing smoothing renewables and island mode operation:
  - smoothing is interconnection requirement for European high penetration solar regions
  - study at Fort Carson showed that the highest cost for peak that we had was when a cloud covered the PV array and it dropped offline
  - Fort Iwrin and Wright Patterson are being directed that they need to be self sufficient at times.
- Utilities look at the power quality at the connection point of DOD bases. Therefore, DOD bases may have a unique opportunity to accrue monetary value by cleaning up power.

EPS Inverter Functions

Basic Inverter Requirements: Anti-Islanding, Local Disconnect, Local Com. Lockout

Advantages: Basic safety requirement

Disadvantage: For high penetration, anti-islanding may require communication at Point of Common Coupling (PCC)

Readiness: Interconnection Standards and Certifications available , devices listed with UL

Grid Supportive Inverter Functions: VAR Support

Advantages: Additional value with no battery discharge degradation and low added inverter cost. Market exists and could be extended to new devices.

Disadvantage: Requires basic communication at PCC. Market for > MW device.

Readiness: Interconnection and object model standards available, not many small inverter devices with this capability are listed with UL.

Advanced Inverter-functions for Generator/Storage devices: Volt-VAR control, Low-Voltage Ride Through (LVRT).

Advantages: Provides additional value from generator/storage without additional battery/energy source usage, and may be required for high penetrations. Low added inverter lifecycle cost.

Disadvantages: Communication at PCC recommended to coordinate with Local Electric Power System (EPS). No established market exist for value provided.

EPS Storage Functions

Regional Storage Functions: Frequency regulation, Peak shaving, Diurnal ramping

Advantages: Replaces function of least efficient and costly generators

Disadvantage: Require communication at Point of Common Coupling (PCC). Degrades battery.

Readiness: Requires only basic load/generation level dispatch Interconnection Standards IEEE 1547 and Certifications UL 1741

Power Quality Storage Functions: Dropped cycles, Flicker, Sags, Solar firming

Advantages: Enhanced power quality for sensitive equipment. Minimal to to moderate degradation. Optimize distribution system and load efficiencies.

Disadvantage: Requires comm. at PCC, asset management for roaming

Readiness: Interconnection and object model standards becoming available, commercial inverters have with these capabilities

Emergency Power and Resilient Micro-grids: Provides fast response microgrid voltage source until other generators become available.

Advantages: Provides additional value from storage device for critical power failure events

Disadvantages: Communication at PCC needed to coordinate with Local Energy Management System (EPS)

Readiness: **IEEE** 1547.4 ready soon and demonstrations ongoing.

PCS Architecture for PEV as Storage

Onboard Propulsion/Grid Inverter:

Advantages: Reduced cost by sharing function with propulsion inverter.

Disadvantage: Requires integration with propulsion system. Advanced storage functions may be difficult to manage with small distributed roaming inverters.

Readiness: Integrated propulsion/grid inverter is not common practice. Power electronics approaches being investigated.

Many vehicles connected to large inverter with DC circuits:

Advantages: Low cost due to reduce number of power electronics stages. Single control point for multiple vehicles / Integrated storage asset management.

Disadvantage: DC circuit safety standards/certifications.

Readiness: Resembles utility-proven PV inverters.

DC Microgrid integrating multiple DC sources:

Advantages: Hierarchical control and management of multiple PEVs, renewables and other DER through single inverter / DC-microgrid. Increase net inverter size to meet minimum for market participation. DC computer data center and lighting application emerging rapidly.

Disadvantages: Relatively new. Standards and Safety Codes still developing.