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

The Pentagon, Arlington VA
June 13, 2011

Agenda (Morning – Before break)

1) US Policy and Programs for Electric Transportation

- **Camron Gorguinpour** (U.S. Air Force – Office of the Assistant Secretary)
  A DOD Perspective on EV Ancillary Services
- **Allen Hefner** (NIST) Introduction and Workshop Goals

9:10am

2) Use of EV as Grid Storage

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

- **Scott Baker** (PJM) ISO/RTO Markets – Freq. reg., Spin res., Peak shave and VARs
- **Willett Kempton** (MAGICC) Demonstration Project - Plugin EVs for Frequency Regulation

9:45am

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

- **Tom Weaver** (AEP) Current Utility Needs for Storage and Ability to Integrate
- **Kevin Schneider** (PNNL) Potential Value of Storage for Distribution System

10:20am **Break**

Agenda (Morning – After break)

10:35am

2) Use of EV as Grid Storage (Continuted)

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?

- **Glenn Skutt** (PowerHub) Inverter/Storage functions to support Renewable Integration
- **William Siddall** (next energy) Storage functions to support Resilient Microgrids

11:10am

Panel D: PEV Battery as Grid Storage - Impact of dual-use on Battery Life Degradation.

- **Dave Nichols** (Altairnano) Impact of grid storage functions on battery degradation
- **Cyrus Ashtiani** (Saft) Impact of duel use on battery – V2G storage and propulsion
- **Eric Hsieh** (A123) Regulatory, Business and Policy issues for PEV as Storage

12:00 **Lunch**

Agenda (Afternoon – Before break)

12:50pm

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?

- **Kathryn Miles** (Eetrex) — Vehicle to grid charging/inverter systems
- **Ron Lacobelli** (Azure Dynamics) — Hybrid Electric Truck Power Electronics
- **Bill Alexander** (Ideal Power Converters) — Multi-port converter: Grid, Battery, and Propulsion

1:40pm:

***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?

- **Leo Casey** (Satcon) — Large Grid-Supportive Inverters for Solar, Storage, and V2
- **Paul Savage** (Emerge Alliance) — DC Microgrids and Applications
- **Mark Earley** (National Electrical Code) — Safety Considerations - Grid Inverters and DC circuits

2:30pm **Break**

Agenda (Afternoon – After break)

2:45pm

4) Transition to PEV Fleet as Storage

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

- **Bruce Gruenewald** (NSI) — Bus Fleet Vehicle-to-Grid Storage
- **John Bryan** (Fleet Energy Company) — Business Development of Vehicle Fleets as Storage

3:20pm

Break-out Session: *Complete Information Charts:*

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?

4:00pm

Discuss Break-out Information Results

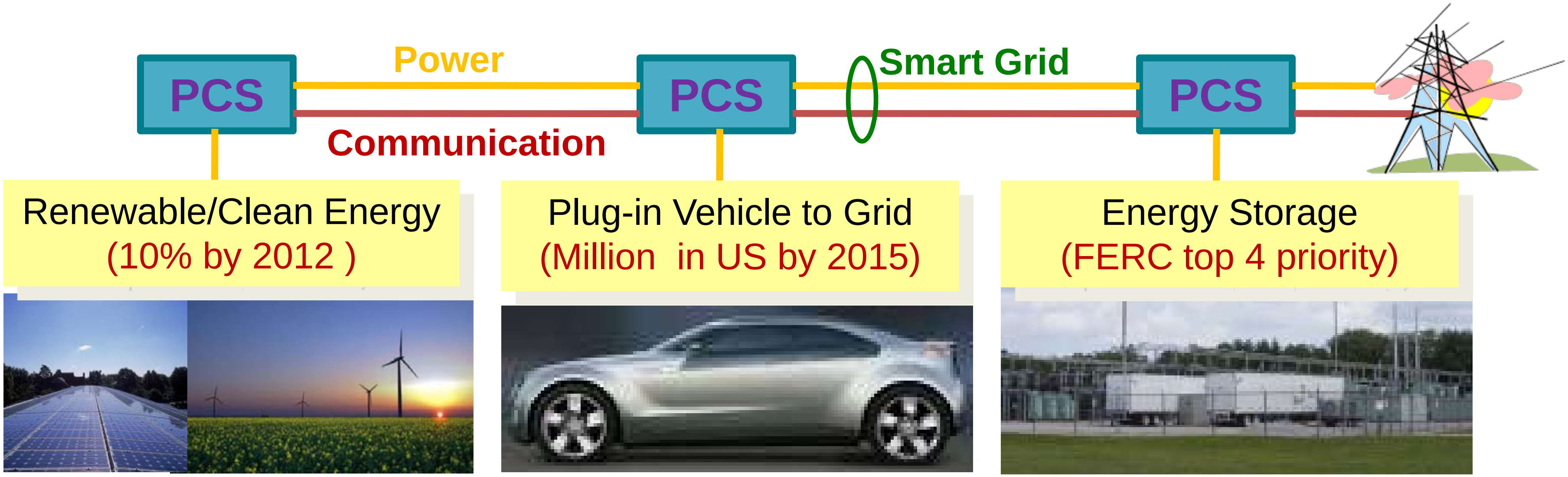
5:00pm **Escort to Metrorail**

NIST High-Megawatt PCS Worskhops

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

- **High-Megawatt Converter Workshop: January 24, 2007**
  - Begin to identify technologies requiring development to meet PCS cost and performance goals for the DOE SECA
- **HMW PCS Industry Roadmap Workshop: April 8, 2008**
  - Initiate roadmap process to offer guidance for further development of high-megawatt converters technology
- **National Science Foundation (NSF): May 15-16, 2008**
  - Establish power electronics curriculums and fundamental research programs for alternate energy power converters
- **Future Large CO2 Compressors: March 30-31, 2009**
  - Prioritize R&D gaps for future CO2 compression systems at large central Coal and Natural Gas plants
- **High Penetration Electronic Generators: Dec. 11, 2009**
  - High-MW electronics required to achieve the goals of high penetration of renewable/clean energy systems

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**

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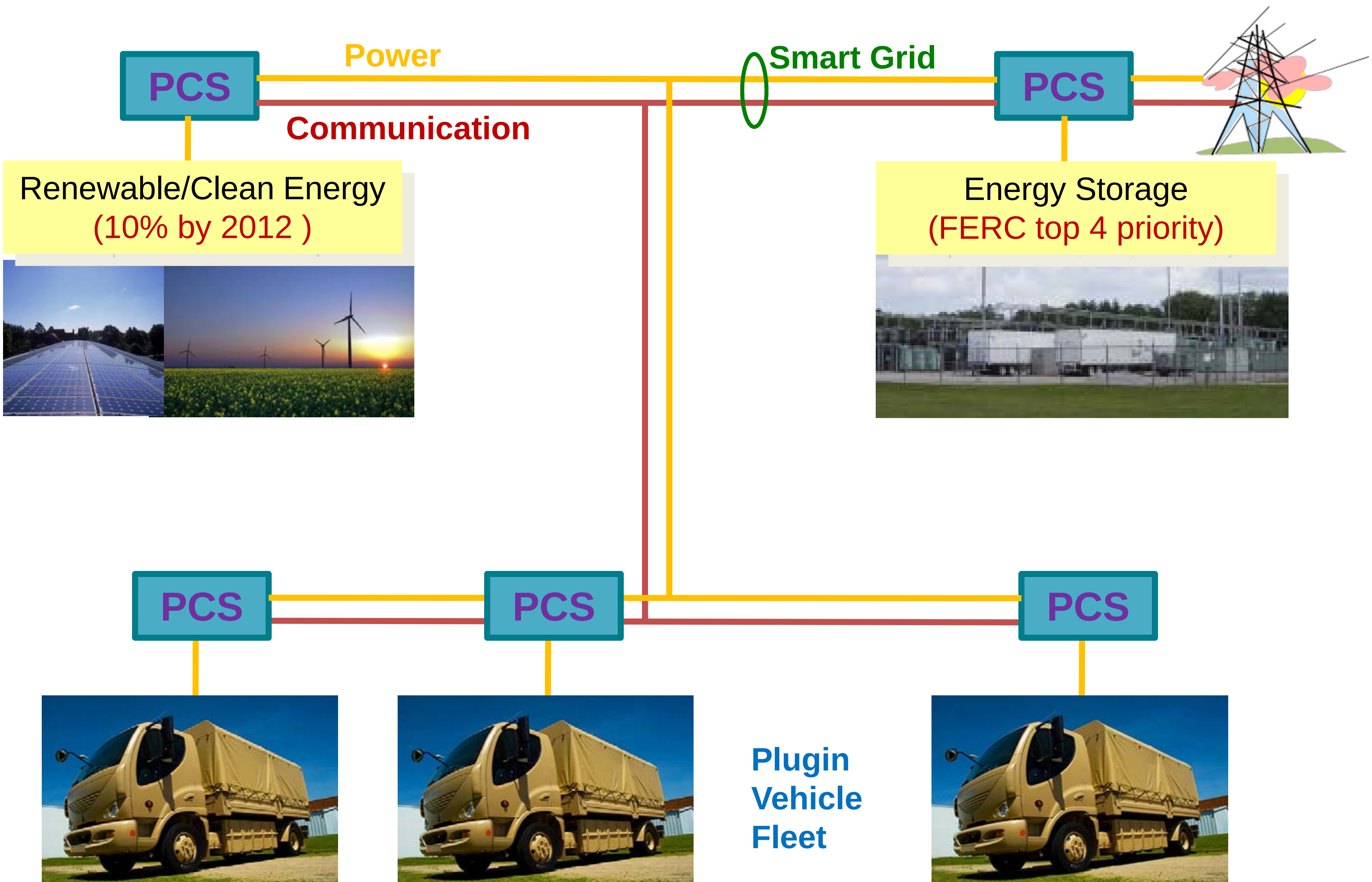
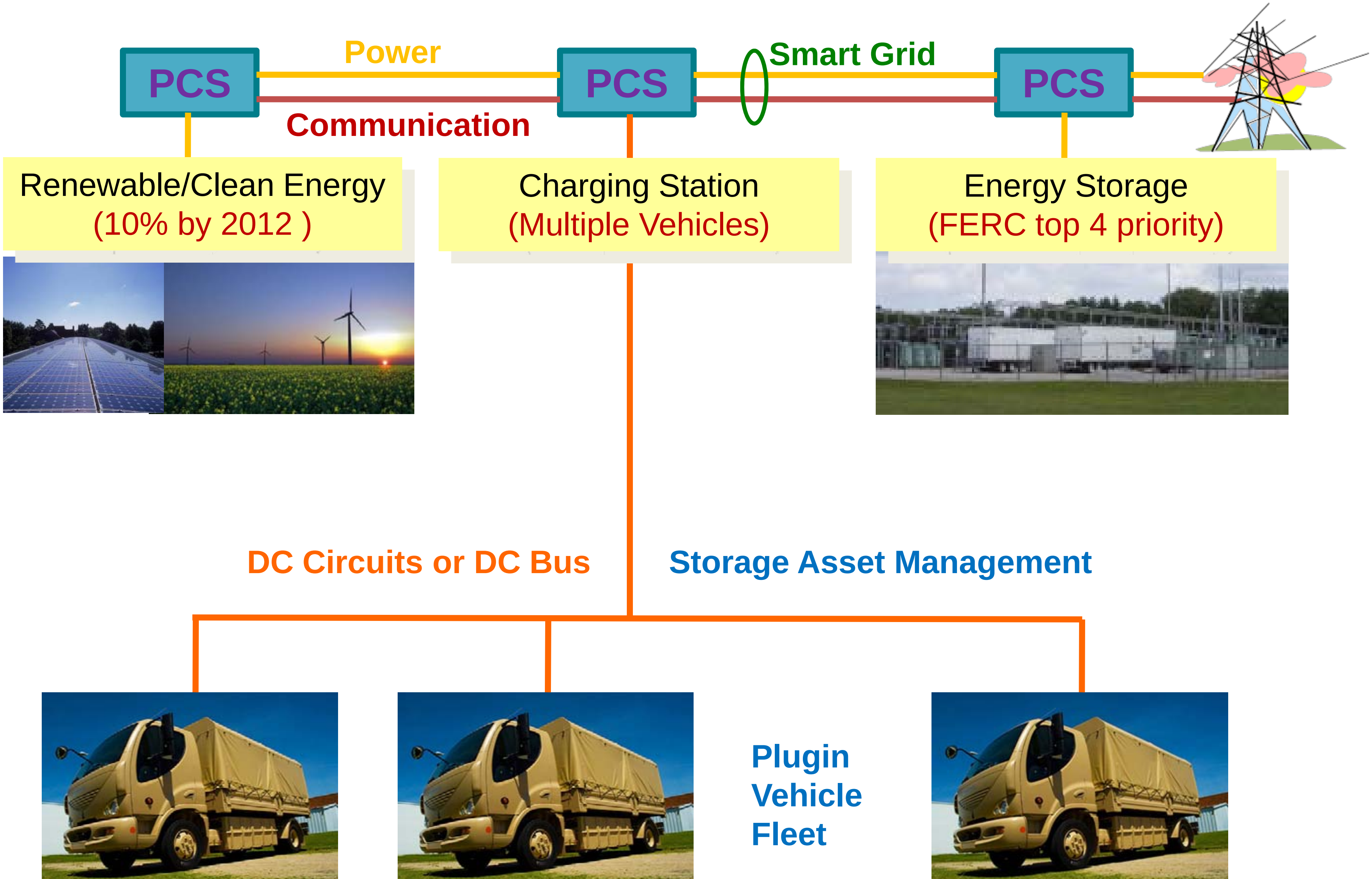
High Penetration of Renewables and PEVs



High Penetration of Renewables and PEVs



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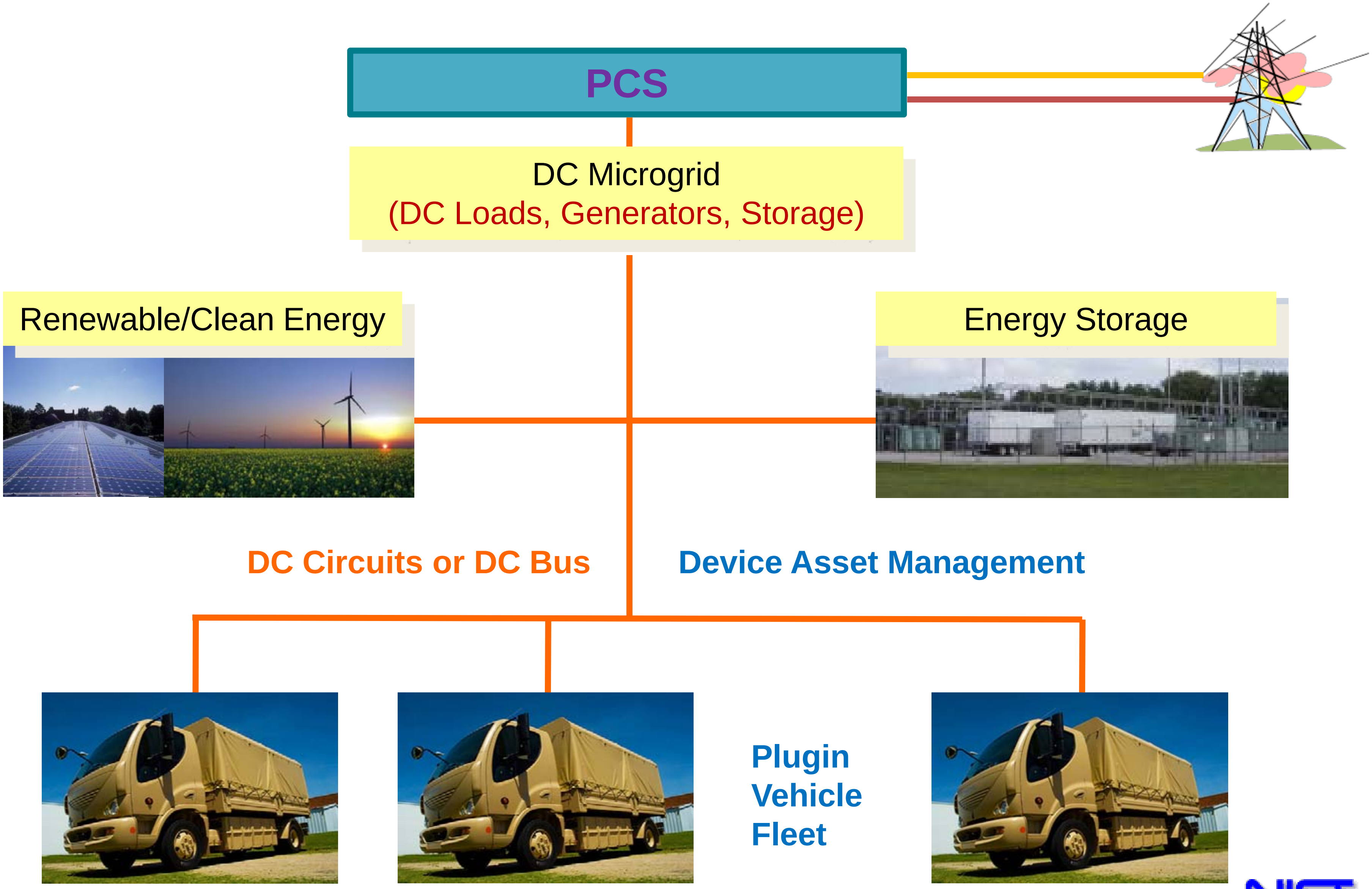
High Penetration of Renewables and PEVs



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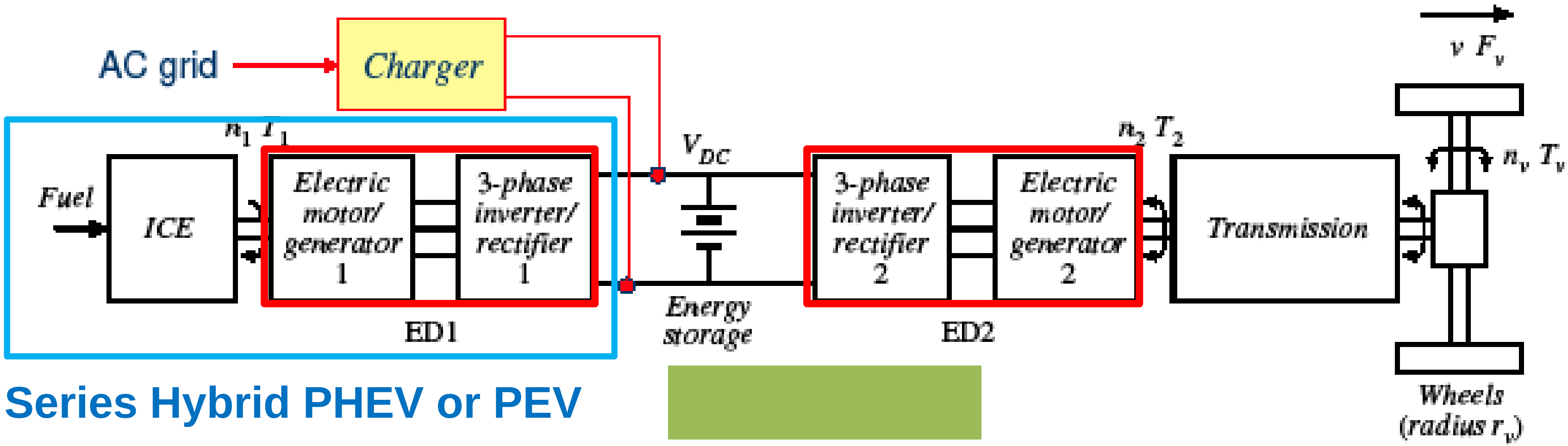
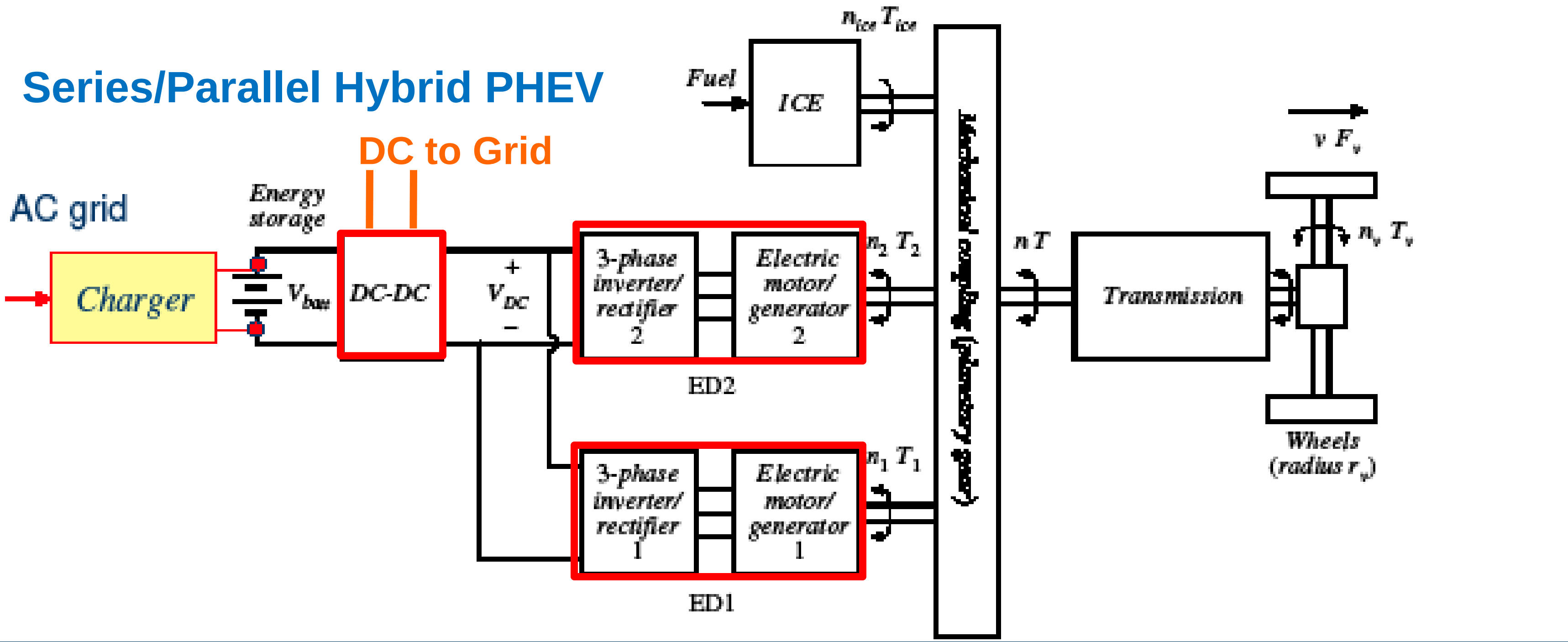
Plug-in Vehicle PCS and Electric Machines



Series Hybrid PHEV or PEV

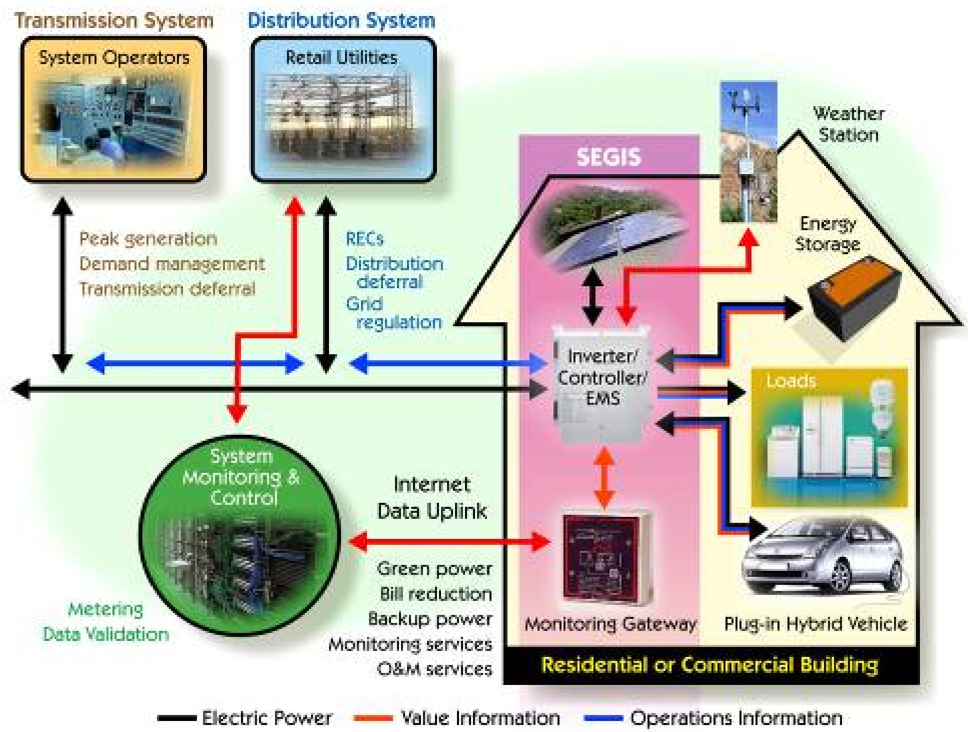


Series/Parallel Hybrid PHEV

Photovoltaic / Distributed Generation

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.



[The Solar Energy Grid Integration System (SEGIS) Integrated with Advanced Distribution Systems]

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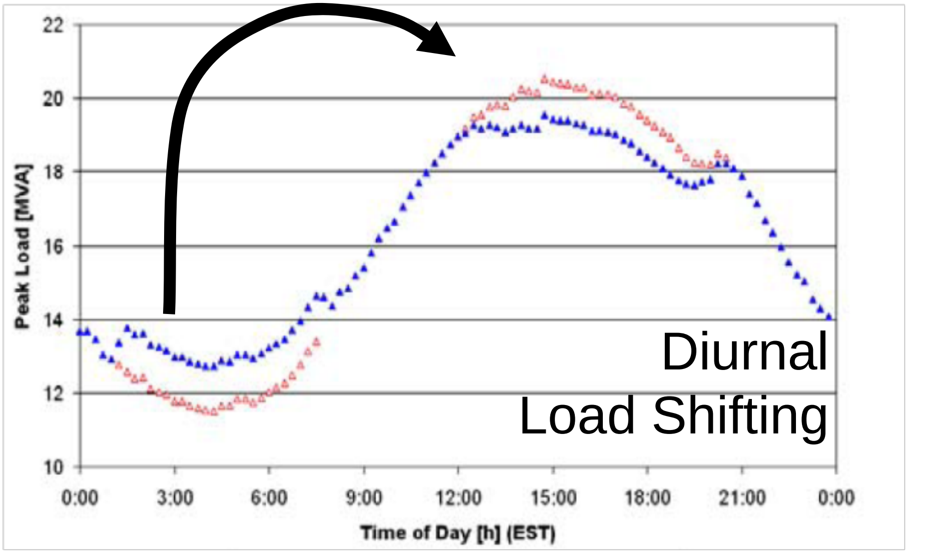
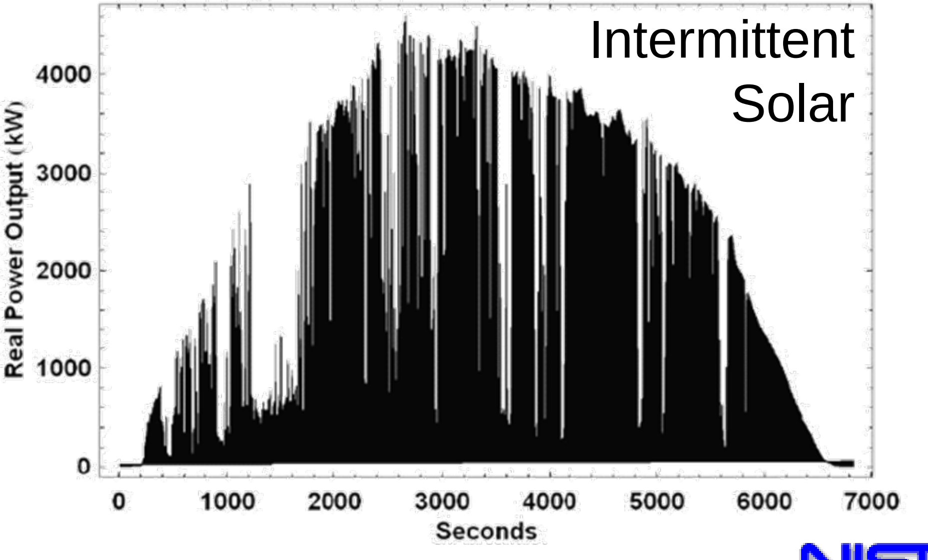
Energy Storage Applications

- **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)

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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)

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Workshop Objectives

- Focus on Fleet Vehicle 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 Fleet type document:
  - advantages and disadvantages
  - technology readiness for 1-5 year timeframe
  - associate approaches with fleet types.

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 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

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

Advantages: Replaces function of least efficient and costly generators

Disadvantage: Require com. 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: Solar firming, Flicker, Sags, Dropped cycles

Advantages: Enhanced power quality for sensitive equipment. Minimal battery 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 current 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 available when?

Readiness: Resembles utility-known PV inverter.

DC Microgrid integrating multiple DC sources:

Advantages: Higharchal control and management of multiple PEV, 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.