Proceedings of

NIST/DOD Workshop on

Power Conditioning System Architectures for Plug-in Vehicle Fleet as Grid Storage

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Proceedings Prepared By

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List of Abbreviations

AC	Alternating Current
AFCI	Arc Fault Circuit Interrupter
A/S	Ancillary Systems
DC	Direct Current
DOD	Department of Defense
DER	Distributed Energy Resource
DRG	Distributed Resource Generator
EPRI	Electric Power Research Institute
ES	Electrical Systems
ETESS-DC	Energy Tank Electricity Storage System-Direct Current
EV	Electric Vehicles
FREG	Frequency Regulation
FY	Fiscal Year
GFCI	Ground Fault Circuit Interrupters
GIV	Grid Integrated Vehicle
GWh	Giga Watt-hour
ICE	Internal Combustion Engines
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
ISO	Independent System Operator
kVA	kilo Volt Ampere
kW	kilo Watt
kWh	kilo Watt-hour
Li	Lithium
MAGICC	Mid-Atlantic Grid Interactive Car Consortium
NEC	National Electric Code
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
OEM	Original Equipment Manufacturer
PCS	Power Conditioning System
PV	Photovoltaic
PEV	Plug-in Electric Vehicles
PHEV	Plug-in Hybrid Electric Vehicles
SMUD	Sacramento Municipal Utility District
SOC	State of Charge
T&D	Transmission and Distribution
TSO	Transmission System Operator
UL	Underwriter Laboratories
UPS	Uninterruptible Power Supply
V2G	Vehicle to Grid
VAC	Volts AC

1. Summary

On June 13, 2011, 43 invited participants convened in a Workshop held at The Pentagon in Arlington, VA. The objective of this Workshop, sponsored by NIST and DOD, was to discuss the characteristics of system architectures that will be required for power conditioning systems in vehicle batteries that can be periodically used to feed electricity to the grid to meet demands for increased power. This approach has been designated as Vehicle to Grid (V2G).

The Workshop began with an introduction by the Workshop Chairman and a Department of Defense (DOD) presentation on their perspective on Ancillary Services (AS) that could be provided by Electric Vehicles (EV). Seventeen additional presentations were then given by selected speakers in seven panel sessions that addressed the following questions:

Panel A	What are existing ancillary service markets where a Plug-in Electric/Hybrid-Electronic Vehicle (PEV) Fleet might participate?
Panel B	What additional grid storage requirements and markets 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	PEV Battery as Grid Storage - Impact of dual-use on Battery Life Degradation?
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?
Panel G	In addition to DOD, what other potential large PEV Fleets might emerge?

When the panel sessions were completed, the Workshop participants were asked to summarize and submit their responses to the following questions:

- 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?

The key conclusions of the Workshop were that:

- The number of PEV vehicles and fleets are expected to increase in size as federal government energy goals for reductions in liquid transportation fuel consumption and carbon emissions are pursued.
- The potential for storage of electricity in vehicle batteries is large. 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.

- The present cost of vehicle batteries is high. Dual use helps spread the cost burden. The cost impact of the addition of electricity storage capability must be factored in.
- Ancillary Services have the potential to provide income to battery owners.
- Injection of relatively small amounts of stored energy into local T&D networks smoothes out grid operation, provides renewable ramp-rate smoothing, and provides fast response power during transition to islanded mode during start up of diesel generators.

Additional conclusions specific to DOD were that:

- DOD has specific targets for reducing liquid fossil fuel (gasoline and diesel) consumption.
- Several DOD bases have specific objectives for security purposes of becoming grid independent islanded operations. In support of that objective, plans are in place to increase the amount of on-base renewable power production.
- A market exists for electricity that can be delivered to the grid for ancillary services from vehicle batteries at DOD facilities.
- 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 improving power quality prior to electricity export.

2. Introduction

On June 13, 2011, 43 invited participants convened in a Workshop held at The Pentagon in Arlington, VA to discuss architectures and technologies for grid connected power conditioning systems used as bidirectional chargers of electric vehicle batteries that also provide grid storage functions. The following description of the workshop was provided to each invited participant.

> *Transportation electrification has become a US national priority emphasized in legislation (such as the Energy Independence and Security Act) and Administration Policy recognizing that it will bring about substantial reductions in petroleum consumption and harmful emissions through increased efficiency and fuel diversity advantages. Plug-in Electric/Hybrid-Electric Vehicles have advanced in recent years to become economically competitive with conventional vehicles, especially when considering the prospect of utilizing the vehicle batteries to also provide certain grid supportive electricity storage functions. In the near term, the economic advantages of vehicles providing grid storage functions might be more readily realized by Fleet Vehicles; such as the US DOD Fleet of non-tactical vehicles.*
>
> *The vehicle charging infrastructure is a key enabler in bringing about the transition to electric transportation. The purpose of this workshop is to identify gaps and opportunities in Power Conditioning System (PCS) architectures and technologies necessary to support the use of a Plug-in Vehicle Fleet as grid storage. The workshop will begin by reviewing the grid storage functions that might increase the value proposition of a Plug-in Vehicle Fleet as well as the impact of these storage functions on vehicle battery life. The grid storage use cases considered to potentially provide economic value for implementation with Plug-in Vehicle batteries will be used to define the functional requirements for the vehicle-to-grid PCS architecture discussions that follow.*
>
> *The status of existing and planned vehicle-to-grid charger/inverter systems will be reviewed during the workshop, and innovative approaches for increasing the value proposition of the vehicle-to-grid PCS will be discussed. For example, advanced vehicle charger/inverter PCS architectures might include: 1) using the on-board propulsion inverters and/or on-board DC-DC converters as part of the grid charger/inverter PCS, 2) using a large inverter for grid interconnection of multiple vehicles and Photovoltaic Solar (PV) arrays, and 3) using DC circuits and micro-grid approaches to reduce the number of required power conversion functions. The readiness of technology and safety codes to implement the advanced architectures will also be highlighted.*
>
> *The workshop concludes with discussions of possible transition strategies for electrification of large Vehicle Fleets including their use for grid storage functions. Vehicle Fleets that might be good candidates for electrification including grid storage functions will be identified and categorized by vehicle type, usage type, and local grid type. For representative Plug-in Vehicle Fleet types, the advantages and disadvantages of various PCS architectures will be discussed and contrasted. The outcome of the workshop is a report defining the PCS approaches, gaps and next steps required to enable electrification of Vehicle Fleets including grid storage functions.*

Introductory remarks reviewing US Policy and Programs for Electric Transportation were made by Camron Gorguinpour, U.S. Air Force – Office of the Assistant Secretary, who provided “A DOD Perspective on EV Ancillary Services”. The objectives of the DOD Electric Vehicle program are:

- Reduce petroleum consumption,
- Reduce greenhouse gas emissions,
- Increase use of Alternative Fuel Vehicles,
- Develop 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 and comparable ICE vehicles,
- Begin large-scale integration of EV within FY2012 to last over a period of 3-5 years.

Al Hefner of NIST, the Workshop organizer, then provided an introduction and workshop goals. The workshop objectives were summarized as follows:

- Focus on PEV Fleet deployment options within the next 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, and
    - appropriate approaches for different fleet types.

Seventeen presentations were then given by selected speakers in seven panel sessions, which included a question and answer period that followed each presentation. The individual panels of selected speakers were charged with responding to the following questions:

Panel A What are existing Ancillary Service markets where a Plug-in Electric/Hybrid-Electronic Vehicle (PEV) Fleet might participate?

- Scott Baker (PJM) - ISO/RTO Markets – Frequency regulation, Spinning reserve, Peak shaving and VARs
- Willett Kempton (MAGICC) Demonstration Project – Plug-in EVs for Frequency Regulation

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 Systems

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

- Glenn Skutt (PowerHub) - Inverter/Storage functions to support Renewable Integration

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

- William Siddall (next energy) - Storage functions to support Resilient Microgrids

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) - Dual-use Energy Storage - Grid and Auto
- Eric Hsieh (A123) - Regulatory, Business and Policy Issues 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

Panel F What are existing ancillary service markets where a Plug-in Electric/Hybrid-Electronic Vehicle (PEV) Fleet might participate?

- Leo Casey (Satcon) - Large Grid-Supportive Inverters for Solar, Storage, and V2G

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

- Paul Savage (Emerge Alliance) - DC Microgrids and Applications
- Mark Earley (National Electrical Code)- Safety Considerations - Grid Inverters and DC circuits

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

These presentations are currently available for review and/or download at:

www.nist.gov/pml/high_megawatt/jun2011_workshop.cfm

When the panel sessions were completed, the workshop participants were asked to summarize and submit their responses to the following questions:

- 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?

3. Integrated Overview of Presentations

A) US Policy and Programs for Electric Transportation

Key Points

- US federal policy is supporting the electrification of the US vehicle fleet to accomplish the following objectives:
    - reducing fossil fuel consumption,
    - reducing air pollution (including CO2),
    - increasing use of alternate fuel vehicles. (Hefner)
- Achieve lifecycle cost parity (or better) between EV and comparable ICE vehicles. (Gorguinpour)
- Begin large-scale integration of PEV within FY2012 to last over a period of 3-5 years (Gorguinpour)
- 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. (Bryan)
- At a projected level of 1,000,000 plug-in vehicles (<1% of registered passenger vehicles on the US roads), each carrying a ~15 kWh store of energy, a sizable 15 GWh distributed storage system could become available. (Ashtiani)

Additional Information Specific to DOD

- DOD is considering an optimal strategy to maximize use of electric vehicles in DOD's non-tactical ground fleet, while minimizing lifecycle investment (Gorguinpour)
- Large, under-utilized non-tactical vehicle fleet is ideal for EV ancillary services
    - 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. (Gorguinpour)
    - Hardware and software exist to integrate EV with micro- and macro-grids. (Gorguinpour)
    - OEM support is necessary for implementation. (Gorguinpour)
    - Revenue estimates range from ~$2,000-$6,000/vehicle, depending on vehicle type. (Gorguinpour)
    - Cost savings estimates from peak shaving are ~$1,200-$1,800/vehicle. (Gorguinpour)
- Financial propositions remain unclear.
    - Revenues/Cost-Savings must be more clearly defined. (Gorguinpour)
    - Bi-directional charging infrastructure costs unclear. (Gorguinpour)
- Operational requirements for DOD fleet must be met. (Gorguinpour)
- Controlled environment on DOD bases enables relatively low-risk technology deployment. (Gorguinpour)
- Continental U.S. military bases are ideally suited as a prototype for green community micro grids (Ashtiani)

- There is an opportunity for DOD to take a leadership role in addressing the nation's looming energy security problem and dependence on foreign oil (Ashtiani)
- Hybrid Intelligent Power for Forward Operating Bases reduces diesel fuel requirements by up to 40% (Alexander)

B) Use of EV as Grid Storage

Key Points (Hefner)

- Economic drivers for off-grid electricity storage include:
    - supplying cost-effective ancillary services,
    - peak load shaving/leveling,
    - more efficient energy arbitrage,
    - premium power for islanding,
    - 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 the typical consumer.
    - Fleet Vehicles with well defined use conditions present a unique opportunity to assure a positive value proposition from V2G
    - Grid storage/inverter functions can have positive and/or negative affects on local and regional 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 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.

Other Detailed Information (Weaver, Ashtiani, Kempton, Schneider)

General Benefits to the Grid of Electricity Storage

- Economic drivers for storage include:
    - Ancillary Services
        - Frequency regulation

        - Spinning reserve
  - Peak load shaving/leveling
    - T&D infrastructure project deferrals
    - Increased utilization of existing generation
    - Load Leveling at substation
  - Premium power for islanding
    - Islanding of Load Area
    - Power Quality
  - Integrating Solar / Wind Generation
    - Smoothing variability
    - Time shifting
  - Network decongestion by time-shifting load or generation
  - More Efficient Energy Arbitrage
    - Charge at lower cost / Discharge at higher value
  - Power Factor Correction
  - Ability to form micro-grids

- **Other Local Benefits of Storage**
  - Backup power (Weaver)
  - Flicker Mitigation (Weaver)
  - Microgrid communities can embody multiple synergistic concepts: distributed renewable generation (DRG), stationary distributed storage resources (community type ES, as well as larger scale for backup power & regulation), EV and PEV, and charging stations within the microgrid (Ashtiani)
  - EV and PEVs within that green community prototype can then become an integral part of the grid, and serve as a last resort rather than day to day functions of the grid (Ashtiani)

- **EV Storage Demonstration Projects**
  - Several demonstration projects have shown that it is technically feasible to provide grid storage functions with PEVs
  - University of Delaware Project (Kempton)
    - Create the Grid Integrated Vehicle (GIV), then operate, permit, and test it
    - Design of Aggregator
      - Provides a single, large, stable and reliable power source
      - Transmission System Operator (TSO) does not see details of single cars, only sees aggregate
      - Aggregator bids capacity in TSO market
      - Dispatches requests to vehicles
      - Reports actual power dispatched
    - Demonstration
      - Seven vehicles in Delaware
      - Each capable of up to 19.2 kW to or from power electronics (versus most OEMs at 3-4 kW charge only)
      - When plugged in, registers with server and offers capacity

        - Battery performance
            - Power response is very close to command signal
            - Far higher fidelity than any rotating equipment
    - Potential contribution of stored EV power to grid
        - US generation capacity ~1000 GW, average load ~450 GW
        - US light vehicles: 200 million
        - At 15 kW/vehicle: 3,000 GW
        - Vehicle batteries: 3x generation, 6x average load
    - Storage at the low-voltage end of the distribution system has value
        - 15 kW & 30 kWh means ~1 hr discharge thus capacity markets, not energy
        - Second use of customer equipment, thus capital costs are controls
        - Need to aggregate many small storage units to get utility-scale power for TSO
    - Capital cost is on-board intelligence plus communications is now ~$400
        - For example, an EV with 15 kW, 30 kWh
        - Capacity cost: $27/kW
        - Storage cost: $13/kWh
    - Recommendations for Power Plug
        - Should be 12 - 20 kW, not 2-6 kW
        - Should be 208 or 240 VAC, not 110 V
        - User convenience: last minute charge or roadside recharge at a mile-a-minute

- Mid-Atlantic Grid Interactive Car Consortium (MAGICC) (Baker)
    - Providing regulation from 5 aggregated vehicles
    - Vehicles primarily used during 7-9 AM, 12-1 PM, and 5-7 PM
    - Vehicles tested in non-use periods for regulation service at 50 ms charge/discharge
    - Over three years experience
    - Also demonstrated minimization of cost by responding to the PJM wholesale price signal (LMP) and the PJM frequency regulation signal in a 105-gallon, 4.5 kW electric water heater

- **Integration of the PEV Fleet with distributed variable renewable generators**
    - Integration of stationary storage with the intermittent load of rapid charging PEVs (Skutt)
        - Proposed 2-3 MW capacity ETESS-DC (Energy Tank Electricity Supply System – Direct Current) to act as dynamic buffer between renewable DC generation (PV, wind, and microturbines) and DC EV charging requirements
        - Requires storage system inverter control and integration with PEV activities
            - Emerging standards for inverter control

            - Inverters are generally underutilized relative to the functionality they can provide
        - Sacramento High Penetration Solar Demonstration Project
            - Control group of 25 homes with PV
                - Residential Group – 15 units
                - UL listed units
            - Community Energy System Group – 3 units
                - Connected to secondary of 50 kVA pad mounted transformers serving 9-12 homes
            - Utility/Customer portals monitor PV, storage, customer load
            - Sending price signals to affect changes in customer usage
            - Quantifying costs and benefits of this storage deployment to gain insights to broader application for SMUD
            - Quantifying costs and benefits of this storage deployment to gain insights to broader application for SMUD

- **Microgrids**
    - The size of the microgrid, the amount of generation and load, matters to the effectiveness of individual and aggregated Plug-in Electric Vehicles (PEVs)
    - Examples include 60-200 kW Forward Operating Base Microgrid Simulation at Fort Irwin, CA and 20-80 MW Wright-Patterson AFB, Dayton, OH
    - PEV Fleet Characteristics are defined by
        - Vehicle Specification: PEV Balance of Parts' Design as presented by Original Equipment Manufacturer (OEM)
        - Vehicle Location: Operational requirements when PEV is not a micro-grid storage device
        - Vehicle Service Time: Operational duty cycle compatibility with micro-grid duty cycle. (Siddall)

- **Battery Performance Degradation**
    - Grid applications are diverse with very different duty cycles:
        - The backup power (UPS) {Uninterruptable Power Supply}, e.g., keeps the storage at high state of charge (SOC) and only occasionally taps into the battery with deep Depth-of-Discharge) at near constant rate (Ashtiani)
        - The frequency regulation (FREG), keeps the battery engaged fully when dispatched with random sharp pulses of a few seconds bi-directionally (charge & discharge). Many shallow cycles superimposed on a usually deep daily Depth-of-Discharge cycle (Ashtiani)
    - Time shifting involves charging and discharging the battery at constant rates intercepted by periods of alternately staying at high and low SOC (Ashtiani)

    - Different duty cycles and loads call for very different system engineering especially from thermal management perspective (Ashtiani)
    - Grid stability is maintained through the balancing of load and supply. Regulation is near zero-energy service compensation for minute-to-minute fluctuations in total system load and uncontrolled generation (Nichols)
    - Incremental additions of "fast" energy storage increasingly stabilizes system frequency (Nichols)

- Battery technologies have different life characteristics dependent on Depth-of-Discharge and number of cycles
    - With Li-ion batteries,
        - At 100% Depth-of-Discharge, one technology provides 3-6 times more cycle life than others
        - At low Depth-of-Discharge cycles, over 1 million cycles and up to 100X more life than others (Nichols)
    - Grid Stabilization and hybrid applications that require many cycles per day result in an expected life of 20 years
    - Peak Shifting at a rate of 1 cycle per day results in an expected life of 50 years
    - Operating at 35 °C compared to 25 °C reduces cycle life by a factor of 1.5 to 2
- In two years of operation in PJM ISO
    - Performed over 250,000 small cycles and charged or discharged over 3,300 MW-hr
    - Less than two percent (<2 %) energy capacity degradation and no significant power capacity degradation
    - Expected to maintain rated power and energy capacity for over twenty years without battery replacements or upgrades (Nichols)
- Field data - 4 MW Battery smoothes ramp rate of 18 MW wind farm to 0.5 MW/min (Nichols)
- Variable charging provides ancillary market revenues without consuming life cycles and has the potential to add end-of-life revenue from remaining battery capacity (Hsieh)
- Full V2G (with bidirectional charging) may not be necessary (Hsieh)
    - Ancillary Services (AS) provide sufficient revenue to spur commercial standalone storage projects
        - Frequency regulation (example of actual revenues)
        - Spinning reserves
        - Renewable ramp management
    - Charge-only operation maximizes useful driving range
    - EVs with variable charging can access Ancillary Service markets within existing policy and market rules (EV acts like DR)
    - Variable-rate charging likely to optimize vehicle performance and cost

C) PCS Architectures for PEV as Storage, Alexander Savage

Key Points (Hefner)

- 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.

Other Detailed Information

- PHEV and EV Characteristics
    - Hybrid electric and electric powertrain products in the commercial vehicle segment PHEV and EVs are already cost and weight challenged – V2G must provide economic return if it is to be utilized in the future
    - Azure's PHEV product has the following performance characteristics
        - 14 kWh Li-Ion battery (nominal = 346 V)
        - electric drive motor continuous power ~50 kW
        - 20 mile electric range (blended)
        - Charge time (240 V) ~ 4 hours
    - Azure's Transit Connect Electric has the following performance characteristics
        - 28 kWh Li-Ion battery (nominal =346 V)
        - Electric drive motor cont. power ~ 57 kW
        - 80 mile electric range UDDS
        - Charge time (240 V/30 A) ~ 8 hours
        - Electric pack design life 10 Years - 120,000 Miles
    - What is the best way to integrate – standalone or with drive inverter and motor? Some level of integration is preferred for lower cost, weight and robustness (Lacobelli)
- Vehicle Charging Energy Storage Design Tradeoffs
    - Concentrated/Centralized vs. Distributed Architectures
    - Energy storage: Mobile storage only vs. stationary + mobile storage
        - Maintaining localized power quality, aggregating/managing energy storage, and meeting demand using only mobile resources presents a formidable challenge at high penetration. Limited by existing infrastructure.

        - Stationary storage could act as a buffer to mitigate these issues, and provide rapid charge capability
    - Integration with PV: Significant advantages compared to standalone energy storage architectures
    - Microgrid**:** PV + battery can provide the basis for a high reliability microgrid (Casey)
- Enhanced Inverter Capabilities Enabled by Energy Storage
    - Improved capacity factor: Small amounts of stored energy can mitigate intermittency of renewables
        - Stationary batteries act as a buffer to absorb rapid variations in plant output power
        - Grid Stabilization: Sub-cycle real and reactive power control
    - Reliability: Enables extended ride through and provides voltage and frequency support for both plant AND grid induced disturbances
    - Utility or PV plant
    - Simplified Integration: Capacity factor and reliability enhancements can be implemented on a *fully localized basis,* (Casey)
- Concentrated Inverters enjoy large cost advantages
    - Two-stage inverter architecture coupled with existing grid-smart inverter capabilities provide a natural platform for integration with stationary or mobile energy storage, mitigate problems and provide synergies
    - Enhances the EV value proposition: Low-cost, fully renewable Level 3 recharge capability, low round trip losses,
    - Simplified integration: PV/EV synergies may be realized with localized, autonomous control (no utility involvement); inverter's point of common coupling and site controller provide a natural gateway for managing V2G services
    - Microgrid: Potential to realize a robust, high reliability AC/DC microgrid (Casey)

Bi-directional EV Components

- Inverger (Miles)
    - Bi-directional battery charger/inverter
    - Intelligent charger uses wind/solar to charge
    - Turn vehicle into clean and quiet generator, powering "critical" home/work components for 2+ days
    - 56 PHEV Conversions to date - over 650,000 miles
    - AC Connection
        - 6.6 kW, Voltage Range: 110 – 240 VAC, Current Range: 12 – 30 A
    - DC Connection
        - Voltage Range: 100 – 400 V, Current Set by AC Connection

- Ideal Power Corporation Bi-directional Battery Inverter/Charger
    - Applications
        - Stationary Batteries
            - 30 kW, 480 VAC, three phase, 60 A
            - 0 to 700 V DC

            - Bi-directional, power-to-grid
        - Vehicle Batteries
            - Bidirectional Level 3 DC charger
            - Power-to-grid
            - Common mode isolated or full isolation
- 3-port PV & Battery Inverter
    - Single-Stage Conversion
        - Higher efficiency
        - Operates during faults
        - Grid faults
    - Communications faults
        - DC charging of EV during peaks
        - Reduce peak load/transmission
    - DC charging of EV during peaks
        - Reduce peak load/transmission
- Ideal Power Corporation PHEV Architecture
    - Multi-port, multi-directional converter
    - Superior efficiency, weight/size, cost
    - Simplified cooling systems
    - Supports inductor generator/motor
    - No Permanent Magnets or rare earths

DC Microgrids (Savage)

- Microgrid applications
    - 24 VDC - Lighting, Computers, Sensors, Fans
    - 380 VDC - Battery Storage, Server Gear, Variable Speed Motor Drives, Vehicle Chargers
- Installations for various applications in offices are increasing

Electrical Code Compliance (Earley)

- Applicable Codes
    - Electrical installation requirements--NEC®
    - Product standards -UL, NEMA, etc
        - Product testing to standards
    - Electrical inspection (ensures compliance with the installation rules of the NEC, along with any product installation requirements
- DC Requirements
    - Have been in every edition since the first NEC edition in 1897.
    - There are specific AC and DC requirements
    - Where not specified, requirements apply to AC and DC
- Higher power DC may present new challenges
    - Over-current protection
    - Ground Fault Circuit Interrupter (GFCI) protection
    - Arc Fault Circuit Interrupter (AFCI) protection
    - Switching
    - Circuit protection

    - Arc flash evaluation
    - Circuit separation

D) Transition to PEV Fleet as Storage

Key Points

- 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 V2G opportunities exist with batteries in 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.

Other Detailed Information

- School Bus Fleets (Gruenewal)
    - Grid operators and utilities have identified PEV V2G capable school buses as an ideal grid storage device for supplying frequency regulation services
    - Predictable usage pattern resulting in availability to the grid of > 75%
    - 77 % of school districts have at least 25 buses
    - Buses are stored in one of three locations: a depot, a school, or a driver's home
    - Average range (with 30 to 50 % margin) can be achieved with a battery of between 100 kWh and 130 kWh
    - 25 PEV V2G buses = 1 MW
- Third Party Ownership of Batteries (Bryan)
    - Fleet Opportunities
        - Transit and school buses
        - Delivery, insurance, utility and waste management company
        - Religious organizations
        - Rail and material transport
    - Fleet Energy owns batteries in commercial vehicles
        - Revenue Stream 1: end user pays "by the mile"
        - Revenue Stream 2: local utility pays "by the hour" for the use of the batteries
    - Fleet Energy operations are highly competitive in regulation and spinning services

4. Issues, Gaps, and Possible Approaches to Issue and Gap Closure

Issues

Technical Issues

- 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?
- Can small sources of battery-stored electricity be aggregated into marketable bundles that can be bid for ancillary service functions and what is the communication/control requirement?
- Who develops the software and communication and cyber security to control and measure operation?
- Is galvanic isolation of V2G systems required?
- Inverter systems may need to be remotely upgradable to take advantages of future advanced inverter/storage functions.
- Electric Vehicle Charging (Casey)
  - EV charging, especially during peak periods, stresses utility infrastructure
  - New charging infrastructure is required for ubiquitous charging capability
- Renewables Intermittency (Casey)
  - Large, sudden changes in solar and wind plant output power can result in power quality degradation (e.g., flicker)
  - Existing grid infrastructure has much slower reaction times than renewable intermittencies

Commercial Issues

- Energy storage costs remain too high for single benefit value streams although they are coming down. Traditional “cost / benefit” analysis sub-optimizes application (Weaver)
- At today’s EV battery and inverter prices, EV have limited commercial competiveness relative to ICE vehicles
- What types of contractual options can be used to provide an economic return to battery owners for V2G functions?
- Who owns the batteries -- fleet owner, individual vehicle owner, leasing company, government unit (DOD), or other?
- How can individual battery owners be compensated for supplying electricity?
- Will there be penalties for failure to deliver?
- Currently, battery and vehicle manufacturers believe fast charging and deep Depth-of-Discharge cycles will negatively impact the life of batteries (Hefner)
  - 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

Regulatory Issues

- How does the V2G system operate in normal operation and during the need for critical resource operation during a reliability compromise?

- When will advanced storage/inverter interconnection practices (IEEE 1547.8) and object model standards (IEC 61850-7-420 normative revision and associated informative update documents) be available?
- What is the acceptable level of power quality delivered by the V2G operator to meet distribution and transmission requirements?

Gaps

Technical Gaps

- Standardized test protocols for EV batteries have not been established (Nichols)
- Bidirectional applications face technical constraints (Hsieh)
- Energy Storage should be "visible and controllable" to distribution operators via SCADA (Weaver)
- Energy storage should have "configurable" control algorithms to allow dynamic changes to meet economic / reliability benefit opportunities (Weaver)
- Integrated inverters (discharge) are not utility scale (MW are required, not kW) (Bryan)
- Lack of "vehicle to utility" standard communication protocols (Bryan)

Commercial Gaps

- Utility contracts are needed and are not simple "demand" programs (Bryan)
- Financial institutions are "wary" of utility market pricing (Bryan)
- Energy storage system warranties are difficult to describe (Bryan)

Regulatory Gaps

- Current IEEE 1547 Guidelines conflict with some benefits (Weaver)

Possible Approaches to Issue and Gap Closure

- Reduce cost and weight of EV batteries and inverters (Lacobelli)
    - There is no single answer => focus on all of the following areas will improve EV adoption:
        - Battery advancements
        - Vehicle and electric drive efficiency gains
        - Fast charging infrastructure => mitigate need of on-board energy
        - V2G and Smart charging => improve cost of ownership
        - Range extender and PHEV options
- Additional Field Test Data (Casey)
    - Real world experience is needed to assess appropriate blend of stationary and mobile energy storage resources

5. Conclusions

- The number of PEV vehicles and fleets are expected to increase in size as federal government energy goals are pursued.
- Potential for storage of electricity in vehicle batteries is large. 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.
- Cost of vehicle batteries is high. Dual use helps to spread the cost burden. The cost impact of the addition of electricity storage capability must be factored in.
- Each vehicle battery requires a control center for prices for buying and selling electricity. Criteria need to be established for rate of charging or discharging, limits on allowable Depth-of-Discharge, and allowable periods for charge and discharge
- Ancillary services have the potential to provide income to battery owners
- Dual use is most valuable where liquid fuel costs are very high.
- Dual use allows capture of additional high value renewable energy where transmission access is limited
- Injection of relatively small amounts of stored energy into local T&D networks smooth out grid operation, provide renewable ramp-rate smoothing, and provide fast response power during transition to islanded mode during start up of diesel generators.

Conclusions Specific to DOD

- 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
- A market exists for electricity that can be delivered to the grid from vehicle batteries at DOD facilities for ancillary services.
- A business model needs to be developed to accrue benefit for providing smoothing renewables and island mode operation.
- Smoothing is an interconnection requirement for European high penetration solar regions
- A study at Fort Carson, CO showed that the highest cost for peak energy was when a cloud covered the PV array and it dropped offline
- Fort Irwin, CA and Wright Patterson AFB, OH 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 improving power quality prior to export.

6. Appendices

A. Final Agenda

NIST Workshop on
Power Conditioning System Architectures
for Plugin-Vehicle Fleets as Grid Storage
(Invitation Only)

Location: The Pentagon, Arlington VA
Date: June 13, 2011
Time: 8am - 5pm

7:30 - 8am: Guests Arrive at Pentagon Station Metrorail stop (see security and travel email).

Upon arriving at the Pentagon Station Metrorail stop, exit through the escalators on the left. At the top of escalators, there will be a Pentagon Visitor Security Line immediately to your left (You will need 2 government-issued IDs as described in the security email to get into the building). Once in the building, you should proceed left to the Visitor Lobby. We will have someone there holding a "NIST" sign who will help you get badged and taken to the conference center.

8:00 - 8:30am: Guests arrive in conference room (escorted in groups).

If guests arrive at the Metrorail stop before 7:30 they will proceed to the visitor lobby as described above and wait until for the first group. If they arrive after 8am they will be late for the meeting but will still be able to attend the remainder of the meeting by calling (703.697.4936).

The agenda will consist of brief presentations and discussions in a Panel Format to address the following areas:

8:30am <u>Workshop Begins</u>

<u>1) US Policy and Programs for Electric Transportation</u>

1.1) Camron Gorguinpour (U.S. Air Force – Office of the Assistant Secretary)
A DOD Perspective on EV Ancillary Services

1.2) Allen Hefner (NIST) - Introduction and Workshop Goals

9:10am

2) Use of EV as Grid Storage

Panel A:

2.1) 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:

2.2) 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

10:35am

Panel C:

2.3) How might a PEV Fleet aid in integration of distributed variable renewable generators?

Glenn Skutt (PowerHub)	Inverter/Storage functions to support Renewable Integration

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

William Siddall (next energy)	Storage functions to support Resilient Microgrids

11:10am

Panel D:

2.5) 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) Duel use Energy Storage - Grid and Auto

Eric Hsieh (A123) Regulatory, Business and Policy issues for PEV as Storage

12:00 Lunch

12:50pm

3) PCS Architectures for PEV as Storage

Panel E:

3.1) What PEV charging and bi-directional charging units are available today?
3.2) 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

3.3) How might large grid inverters be used to integrate multiple vehicles and other generator/storage devices?

Leo Casey (Satcon) Large Grid-Supportive Inverters for Solar, Storage, and V2G

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

Paul Savage (Emerge Alliance) DC Microgrids and Applications

Mark Earley (National Electrical Code) Safety Considerations - Grid Inverters and DC circuits

2:30pm <u>Break</u>

2:45pm

<u>4) Transition to PEV Fleet as Storage</u>

Panel G:

4.1) 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

Each Table Completes Information Charts for:

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

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

4:00pm *<u>Wrap Up:</u>*

Each Table Presents Information Charts and All Attendees Comment and Merge

5:00pm <u>Escort to Metrorail</u>

B. List of Attendees

Name	Email Address	Affiliation
Tarek Abdallah	Tarek.Abdallah@erdc.usace.army.mil	ERDC-CERL-IL
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Scott Baker	bakers1@pjm.com	PJM Interconnection
John Bryan	john@fleet-energy.com	Fleet Energy
Leo Casey	Leo.Casey@satcon.com	Satcon
David Ciembroniwicz	dciembronowicz@methode.com	Methode Electronics
Rajib Datta	datta@ge.com	GE Global Research
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Mark Earley	mwearley@nfpa.org	NFPA, National Electrical Code
Camron Gorguinpour	Camron.Gorguinpour@pentagon.af.mil	Airforce, Office of Assistant Secretary
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Tom Weaver	tfweaver@aep.com	AEP
Ron Wolk	ronwolk@aol.com	Consultant
Robert Wood	rawood@arl.army.mil	ARL

C. List of Workshop Presentations

Bill Alexander, Ideal Power Converters
Current-Modulation Electronic Power Converters

Cyrus Ashtiani SAFT
Dual Use of PEV Batteries: V2G Storage and Propulsion

Scott Baker, PJM Interconnection
Electric Vehicles and Wholesale Markets

John Bryan, Fleet Energy
A Utility's Energy Storage and Fleet's Mileage Service Provider

Leo Casey, Satcon
Large Grid-Supportive Inverters for Solar, Storage, and V2G

Mark W. Earley, National Fire Protection Association
Infrastructure Codes and Standards - the National Electrical Code® - Electric Vehicles and DC Power

Camron Gorguinpour, Office of the Assistant Secretary of the Air Force
A DOD Perspective on EV Ancillary Services

Bruce Gruenewald, National Strategies
Bus Fleet Vehicle-to-Grid (V2G) Storage

Allen Hefner, NIST
Introduction to the NIST Workshop on Power Conditioning System Architectures for Plugin-Vehicle Fleets as Grid Storage

Eric Hsieh, A123 Systems
Business and Policy for Plug-In Vehicle Grid Uses

Willett Kempton, University of Delaware
Demonstration: Plugin EVs for Frequency Regulation

Ron Lacobelli, Azure Dynamics
AZD Power Electronics for Hybrid Vehicles

Kathryn Miles, Eetrex Incorporated
Inverger Technology

Dave Nichols, Altairnano
Impact of Grid Storage Functions on Battery Degradation

Paul Savage, Emerge Alliance
DC Microgrids and Applications

Kevin Schneider, PNNL
Potential Value of Storage for Distribution Systems

Bill Siddall, Next Energy
How Might A PEV Fleet Aid In Integration Of Resilient Micro-Grids? (Storage Functions To Support Resilient Micro-Grids)

Glen Skutt, powerhub SYSTEMS
Inverter/Storage Functions to Support Renewable Integration

Tom Weaver, AEP
Energy Storage at AEP

1) US Policy and Programs for Electric Transportation

Session 1.1
Gorguinpour

A DOD Perspective on EV Ancillary Services

NIST Workshop:
Power Conditioning System Architectures for Plug-In Electric Vehicle Fleets as Grid Storage

June13, 2011

Presented by
Camron Gorguinpour, PhD
Special Assistant
Office of the Assistant Secretary of the Air Force
Installations, Environment & Logistics
Camron.Gorguinpour@pentagon.af.mil

Overview

- EV Project Objectives
- DOD Fleet Overview
- Strategies to Improve EV Financial Picture
- EV Ancillary Services
  - Rationale for Exploration
  - Considerations & Opportunities
- Current/Upcoming Activities
- Conclusion & Discussion

EV Project Objectives…

- Reduce Petroleum Consumption
- Reduce Greenhouse Gas Emissions
- Increase Use of Alternative Fuel Vehicles

EV Project Objectives
(continued)

- Develop 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 EV's within FY2012 to last over a period of 3-5 years.

Current Fleet Statistics

Total # Non-Tactical Vehicles: ~194,710		
Vehicle Type	**% of Fleet**	**Ave. Annual Miles**
MD Trucks*	22%	6251
LD 4x2 Trucks	15%	7690
LD Pass. Vans	11%	9043
Compact Sedans	9%	~16325
Midsize Sedans	9%	~16325
HD Trucks	9%	3516

*Largest Fuel Consumer in DOD Non-Tactical Fleet: ~43 M gallons of petroleum/year

EV/PHEV Opportunities

Vehicle Class	Est. # OEM's
MD Truck/Van	10
LD 4x2 Truck	2
LD Pass. Van	4
Compact Sedan	10
Mid-Size Sedan	13
HD Truck	0

- MD Trucks/Vans present the greatest opportunity for impact in DOD's non-tactical fleet, by volume, petroleum consumption, and variety of manufacturers.
- MD Trucks/Vans typically have well-defined duty cycles, which makes it easier to "right-size" batteries.

Strategies for Improving EV Financial Outlook

Volume Pricing

- DOD's non-tactical ground fleet consists of ~200,000 vehicles.
- Annual volumes in the 10,000's can significantly reduce price of EV sedans.
    - Passenger sedans compose ~20% of fleet.
- Annual volumes of ~1,000 can significantly reduce the price of EV trucks.
    - LD/MD/HD trucks compose ~52% of fleet.

Battery Right-Sizing

- DOD MD/HD trucks average ~6,000/3,000 miles per year, respectively.
- A significantly downsized battery can provide the same functionality as ICE trucks for the vast majority of DOD applications.
- Goal for battery right-sizing is to match the battery size to the average daily range, as close as possible.

Ancillary Services

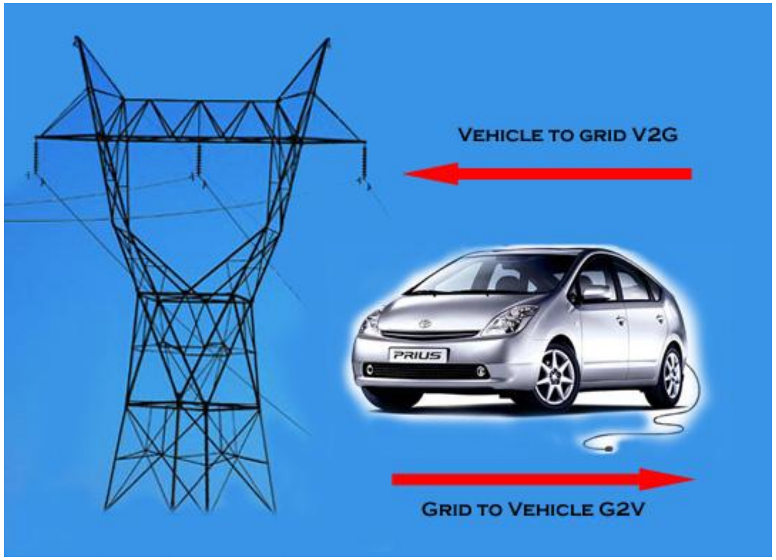
- Hardware and software exist to integrate EV's with micro- and macro-grids.
    - OEM support necessary for implementation.
- Revenue estimates range from ~$2,000-$6,000/vehicle, depending on vehicle type.
- Cost savings estimates from peak shaving are ~$1,200-$1,800/vehicle.
- Dependent on regional/local conditions.
- Supports base-level energy management.

Infrastructure Planning

- Cost of EV charging hardware is minimal, particularly with volume.
- Infrastructure improvements may be significant but vary by location.
- Co-locating multiple EV chargers may significantly reduce installation costs.
- Baseline analyses underway.
- Studying costs associated with various bi-directional charging architectures.

Why EV Ancillary Services?

- Financial Benefits
- Micro-Grids and Grid Security
- Potential GHG Emission Reductions
- Asset Management
- Impact on Broader EV & Utility Industries



Considerations & Opportunities

- Large, under-utilized fleet is ideal for EV ancillary services
- Financial propositions remain unclear.
  - Revenues/Cost-Savings must be more clearly defined.
  - Bi-directional charging infrastructure costs unclear.
- Operational requirements for DOD fleet must be met.
- Controlled environment on DOD bases enables relatively low-risk technology deployment.

Current/Upcoming Activities

- **Objective:** Establish detailed understanding of the costs, benefits, and operational considerations for using EV's as grid energy storage devices.
- Planning base-level analyses for EV ancillary services and corresponding infrastructure.
- Hosting DOD working session on June 17.
- Continuing industry market research.
- Investigating opportunities to conduct relevant technology demonstrations.

Conclusion

- The DOD EV project is expanding rapidly, and we are engaging industry, academia, and government on multiple fronts.
- EV ancillary services may play a critical role in maximizing the scope and scale of DOD's overall EV effort.
- Analyses and activities currently underway to help generate cost/benefit analyses.
- This workshop is an excellent opportunity for DOD to gather ideas toward an actionable short-term plan.

Questions?

1) US Policy and Programs for Electric Transportation

Session 1.2
Hefner

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

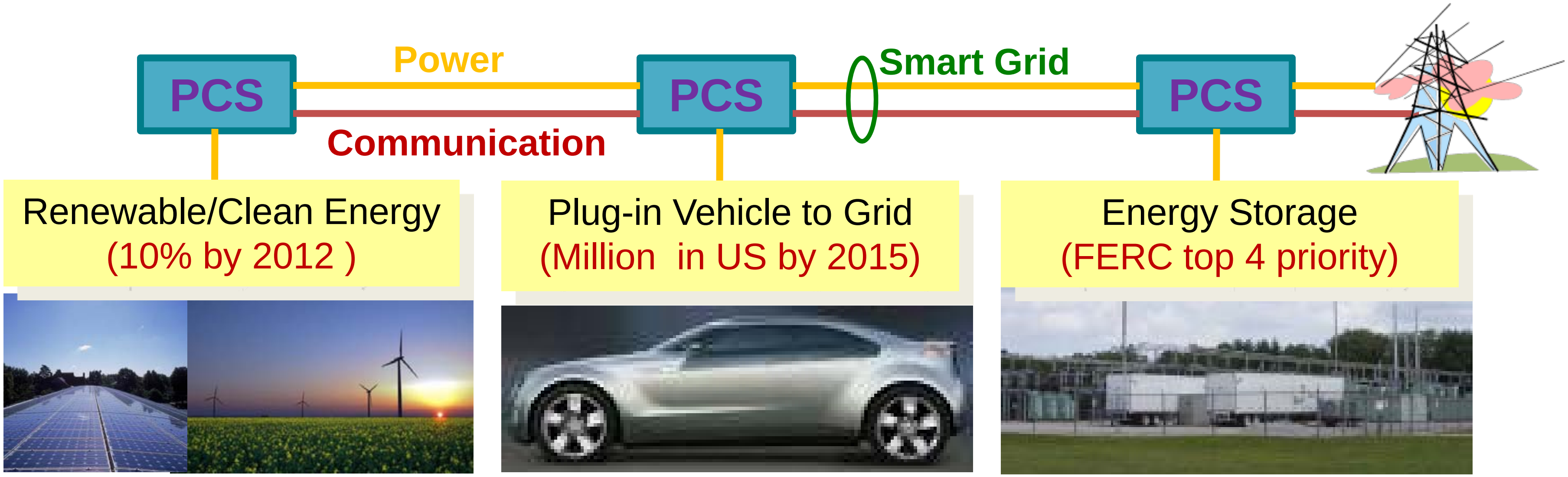
5:00pm **Escort to Metrorail**

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**

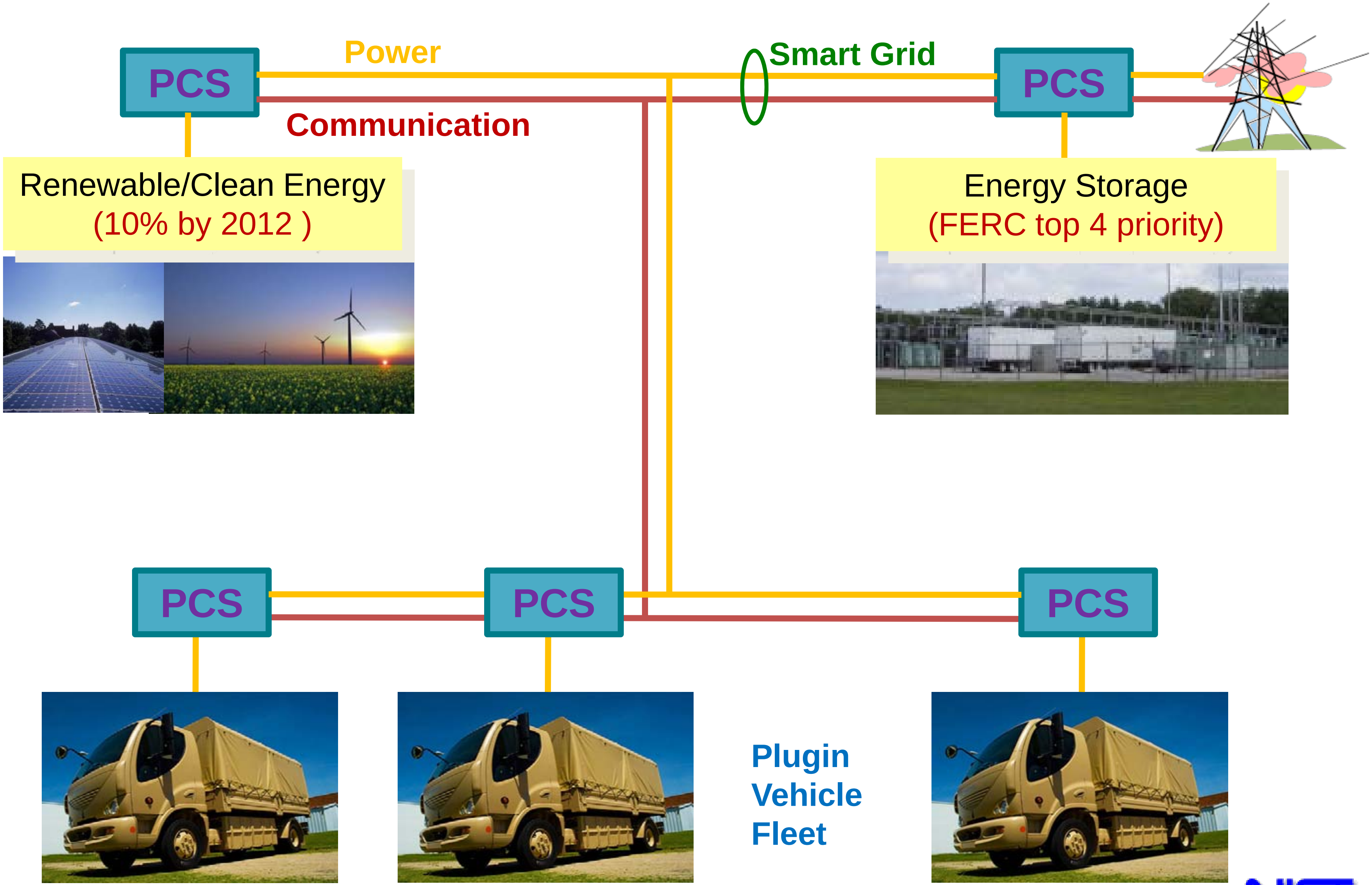
High Penetration of Distributed Energy Resources



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

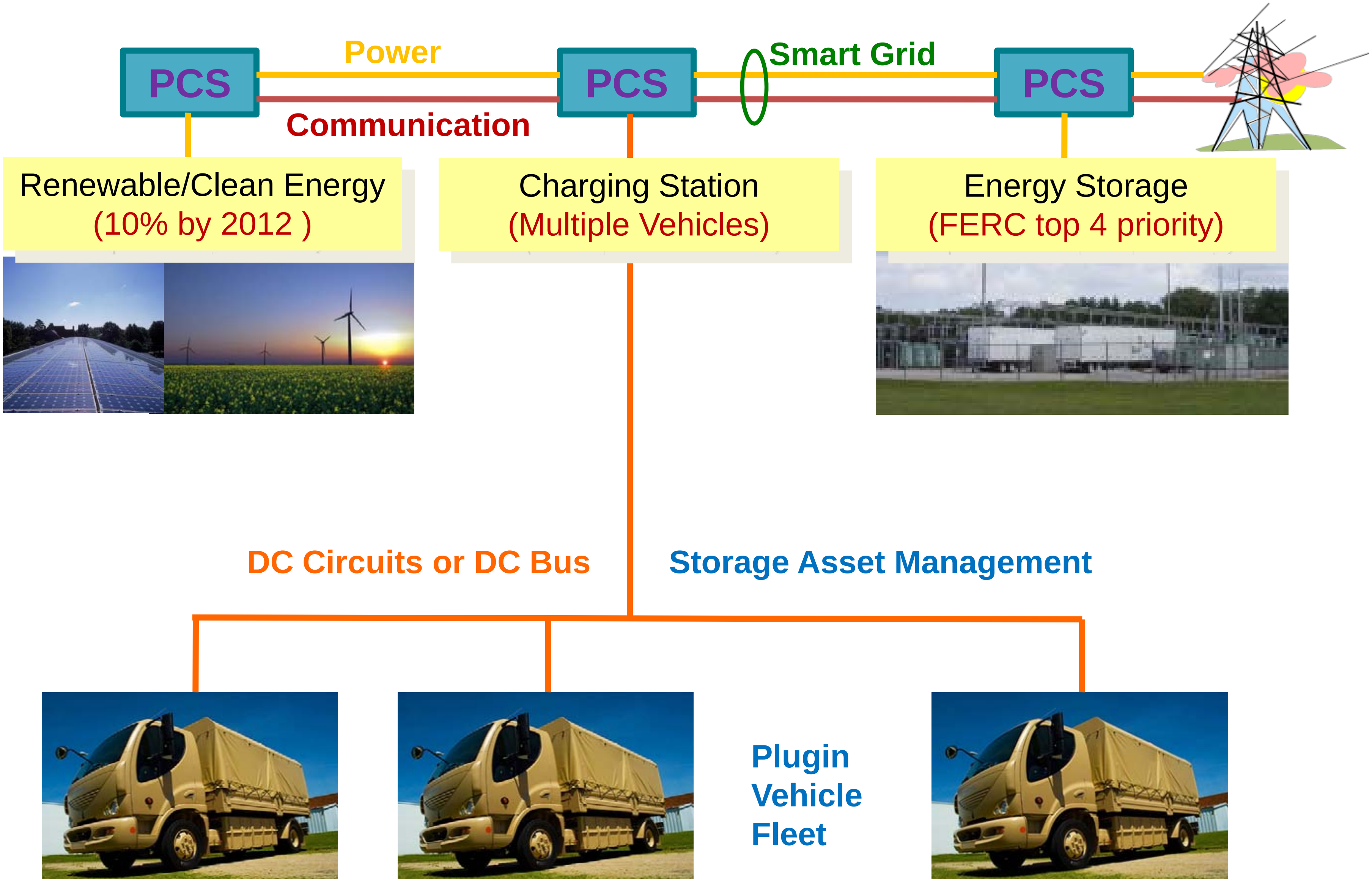
- "Smart Grid Interconnection Standards" required for devices to be utility controlled operational asset and enable high penetration:
  - **Dispatchable real and reactive power**
  - **Acceptable ramp-rates to mitigate renewable intermittency**
  - **Accommodate faults faster, without cascading area-wide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

High Penetration of Renewables and PEVs



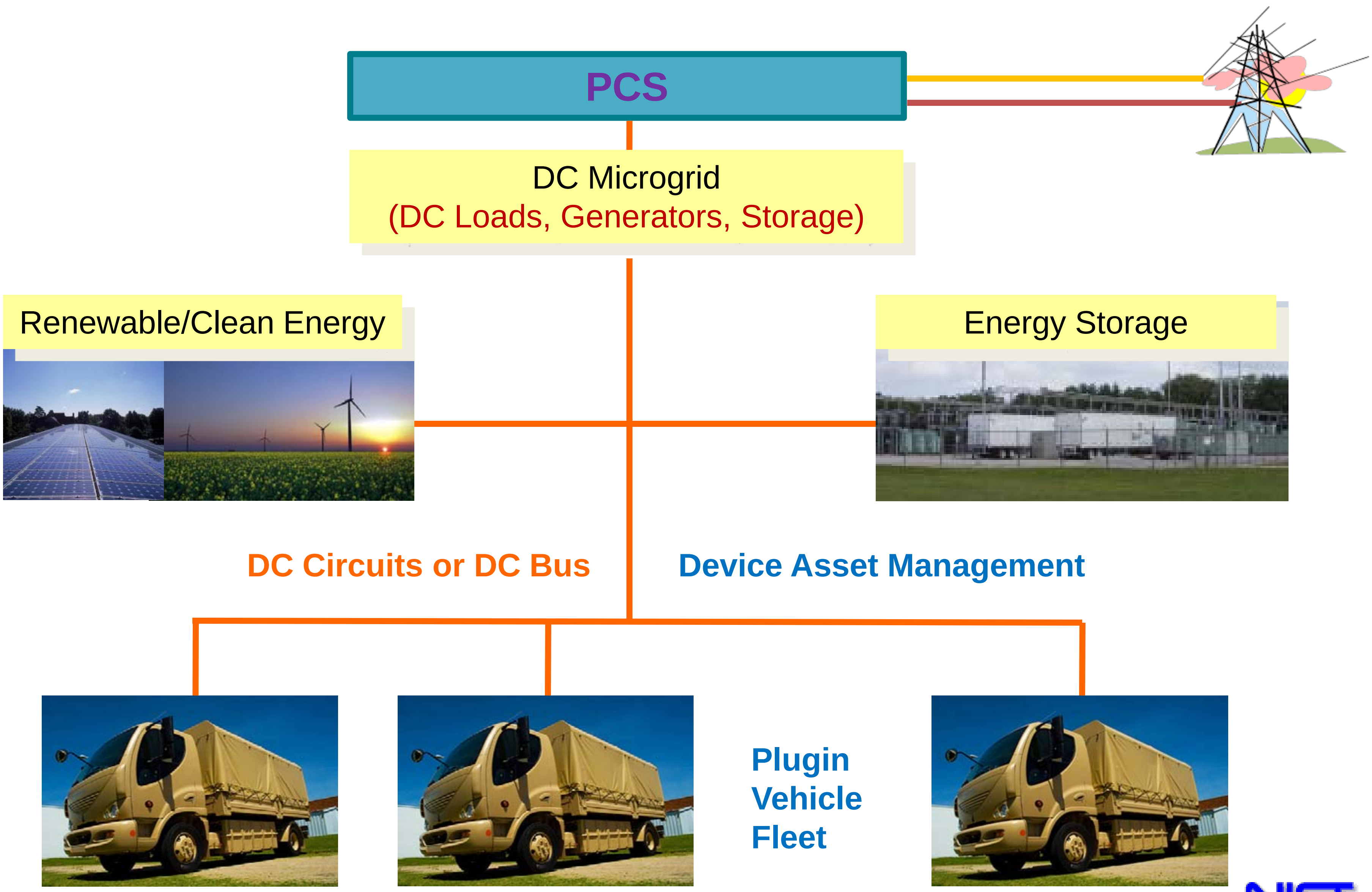
National Institute of Standards and Technology

High Penetration of Renewables and PEVs



NIST
National Institute of Standards and Technology

High Penetration of Renewables and PEVs



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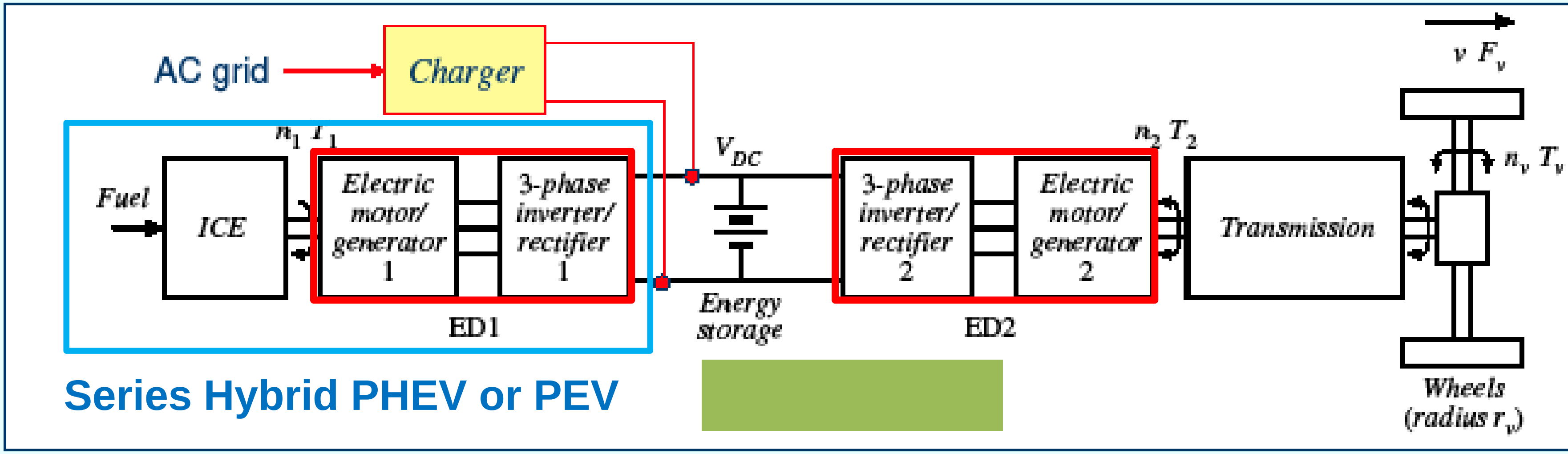
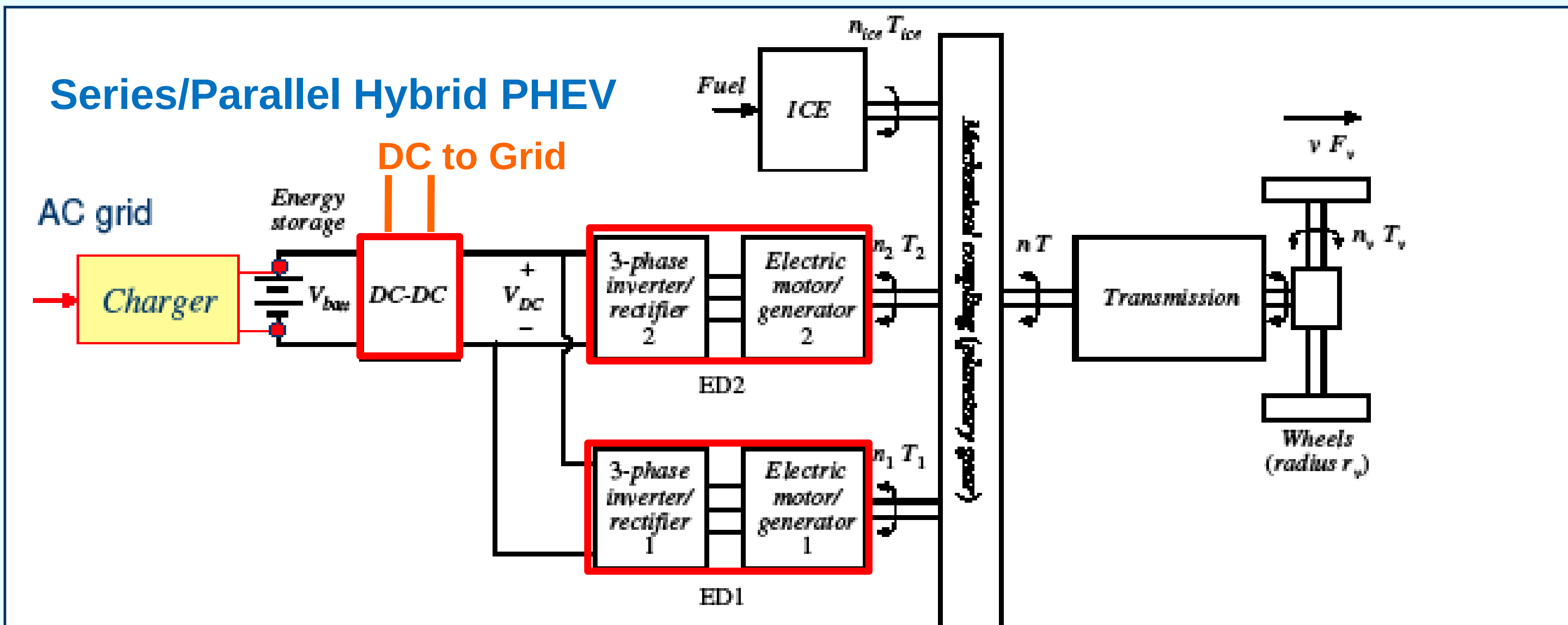
Standards and Technology

Plug-in Vehicle PCS and Electric Machines

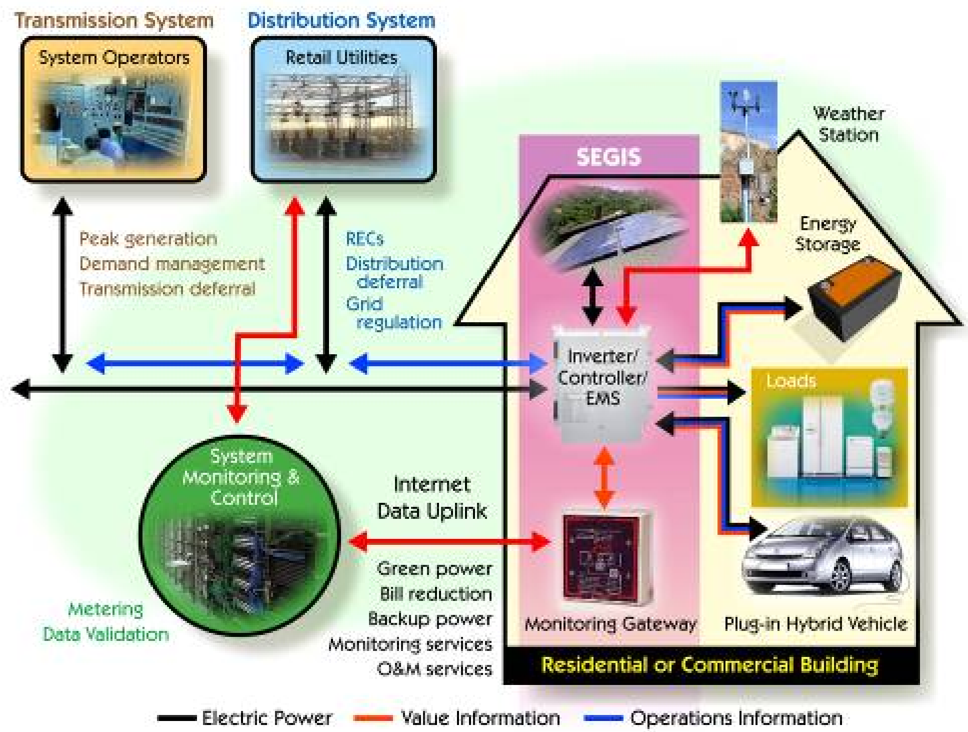




Photovoltaic / Distributed Generation

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

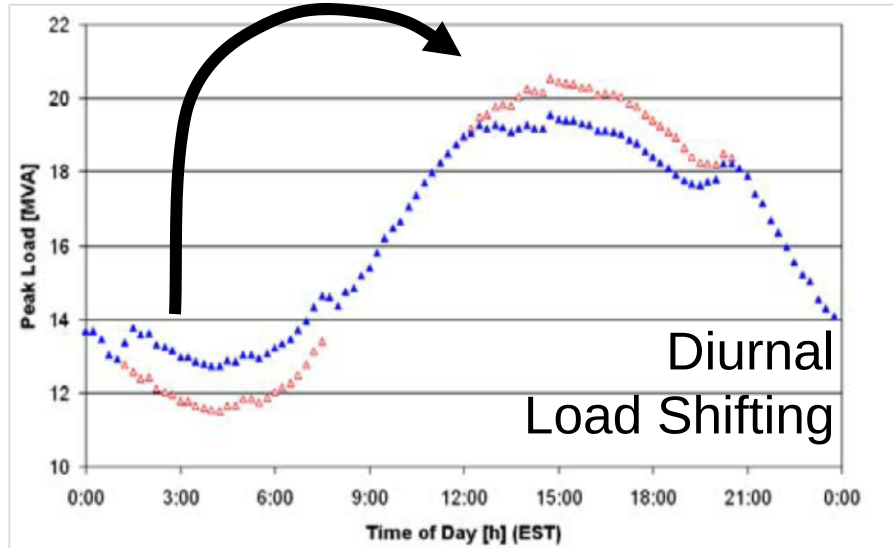
NIST National Institute of Standards and Technology

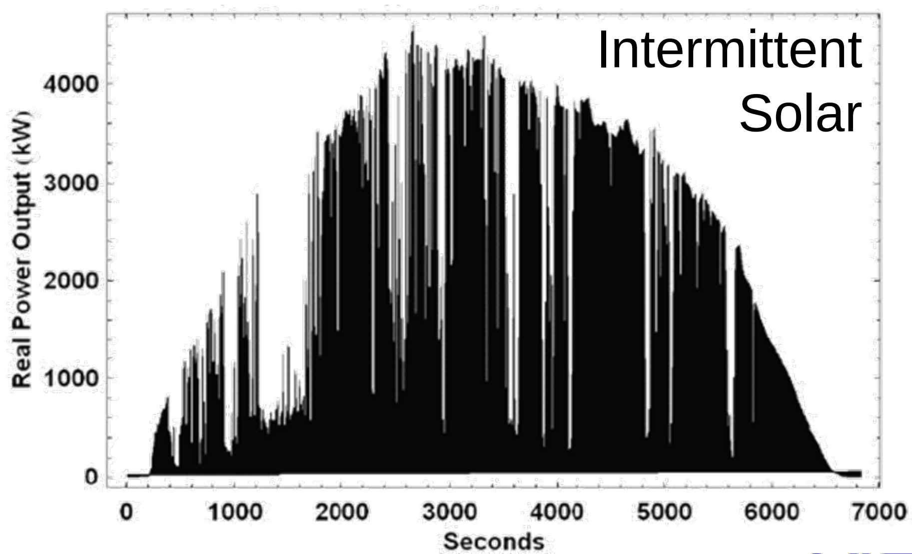
Energy Storage Applications

- **Today's <u>Grid</u>** connects electricity
  WHERE it is needed,
  <u>Storage</u> 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)

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.

2) Use of EV as Grid Storage

Session 2.1

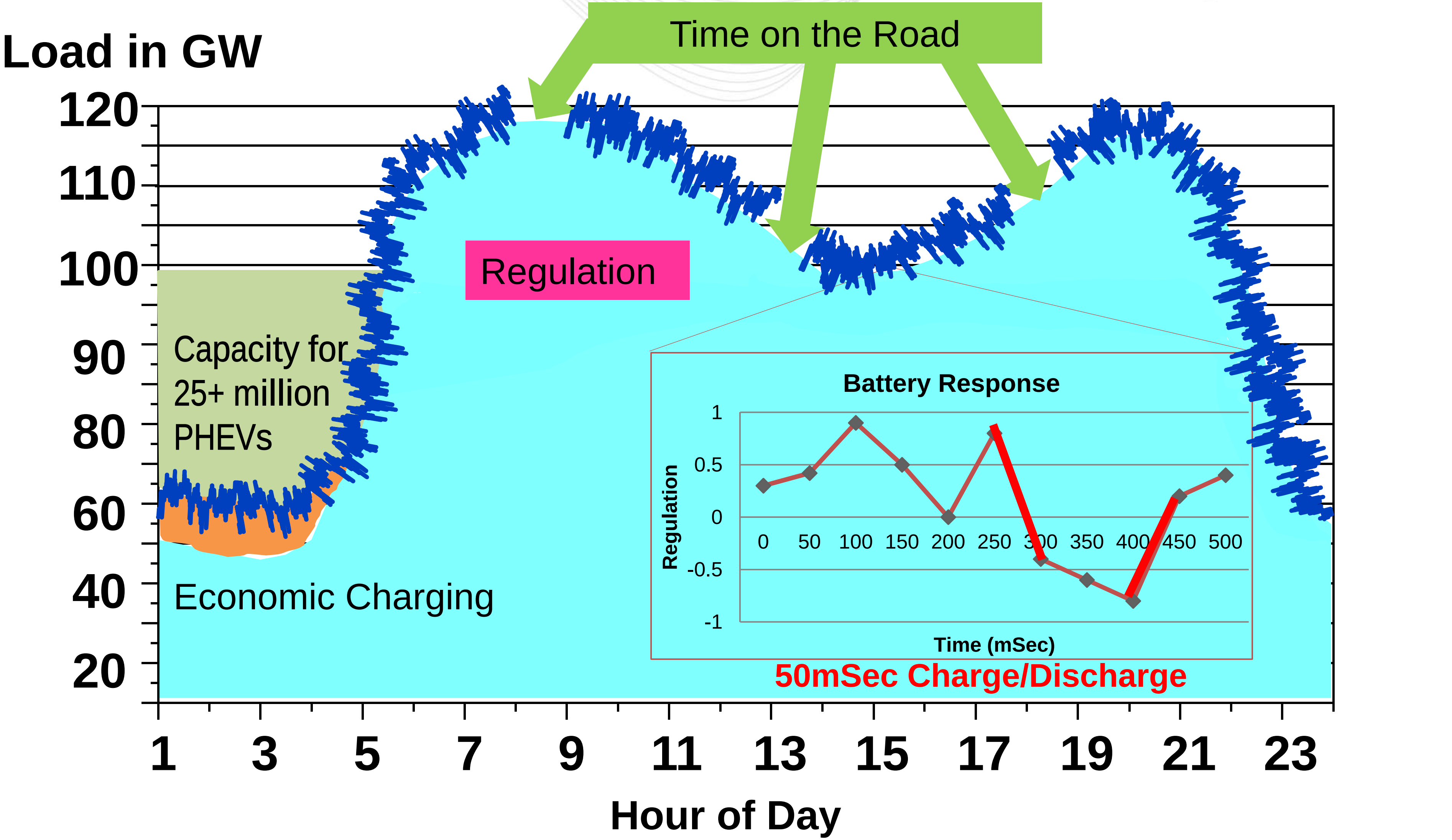
Baker

Electric Vehicles and Wholesale Markets

Power Conditioning System Architectures for PEV Fleets as Grid Storage
The Pentagon
June 13, 2011

Scott Baker
Business Solutions Analyst
Applied Solutions
bakers1@pjm.com

Grid Benefits – Regulation vs. Economic Dispatch



MAGICC – PJM's PHEV Demonstration Project

- Mid-Atlantic Grid Interactive Car Consortium (MAGICC)
- Providing Regulation from 5 aggregated vehicles
- **Over three years experience**

University of Delaware

Pepco Holdings Inc

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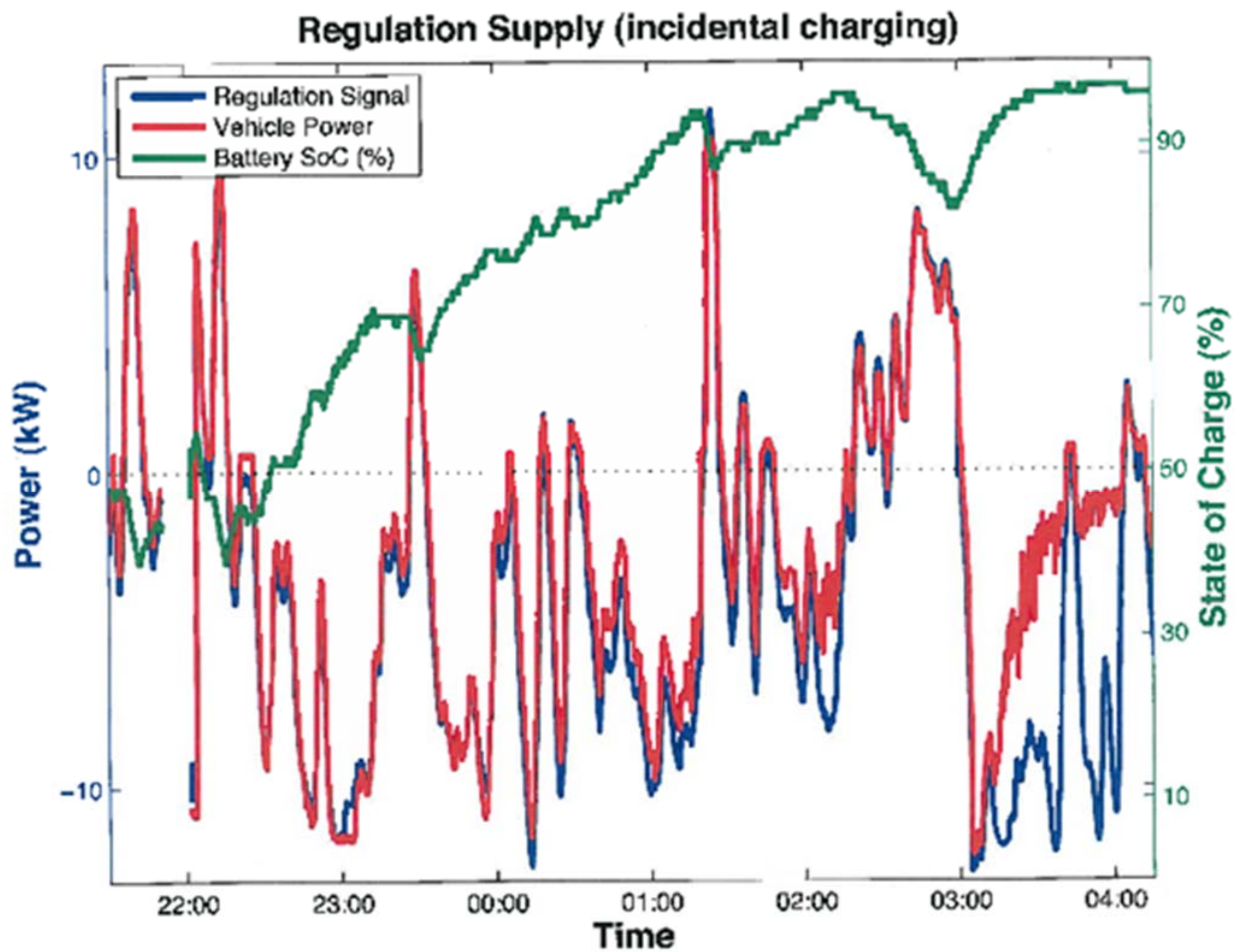
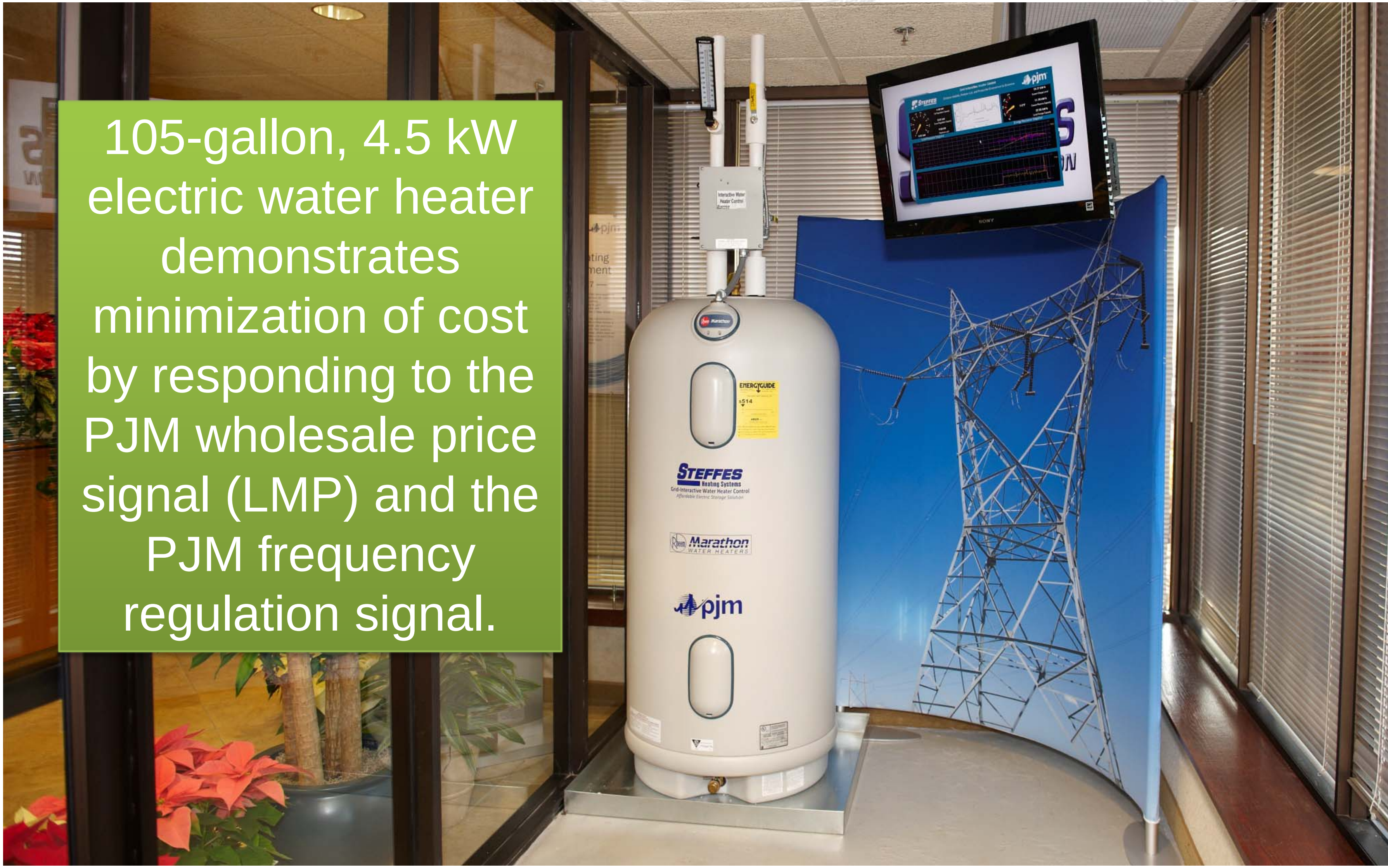
MAGICC – PJM's PHEV Demonstration Project



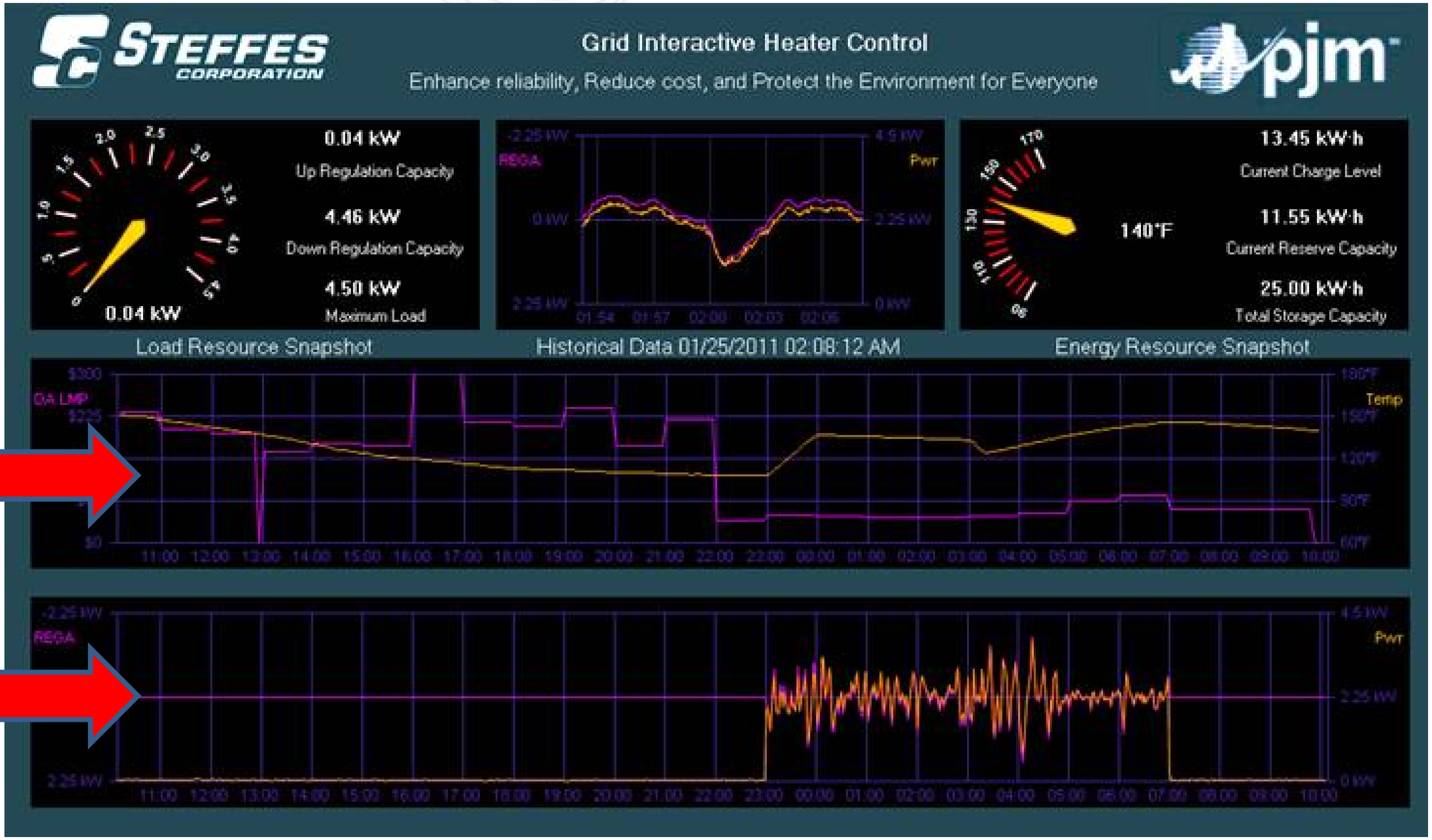


105-gallon, 4.5 kW electric water heater demonstrates minimization of cost by responding to the PJM wholesale price signal (LMP) and the PJM frequency regulation signal.

Water Heater – Optimization of LMP and Frequency Regulation

Charging during low LMP periods

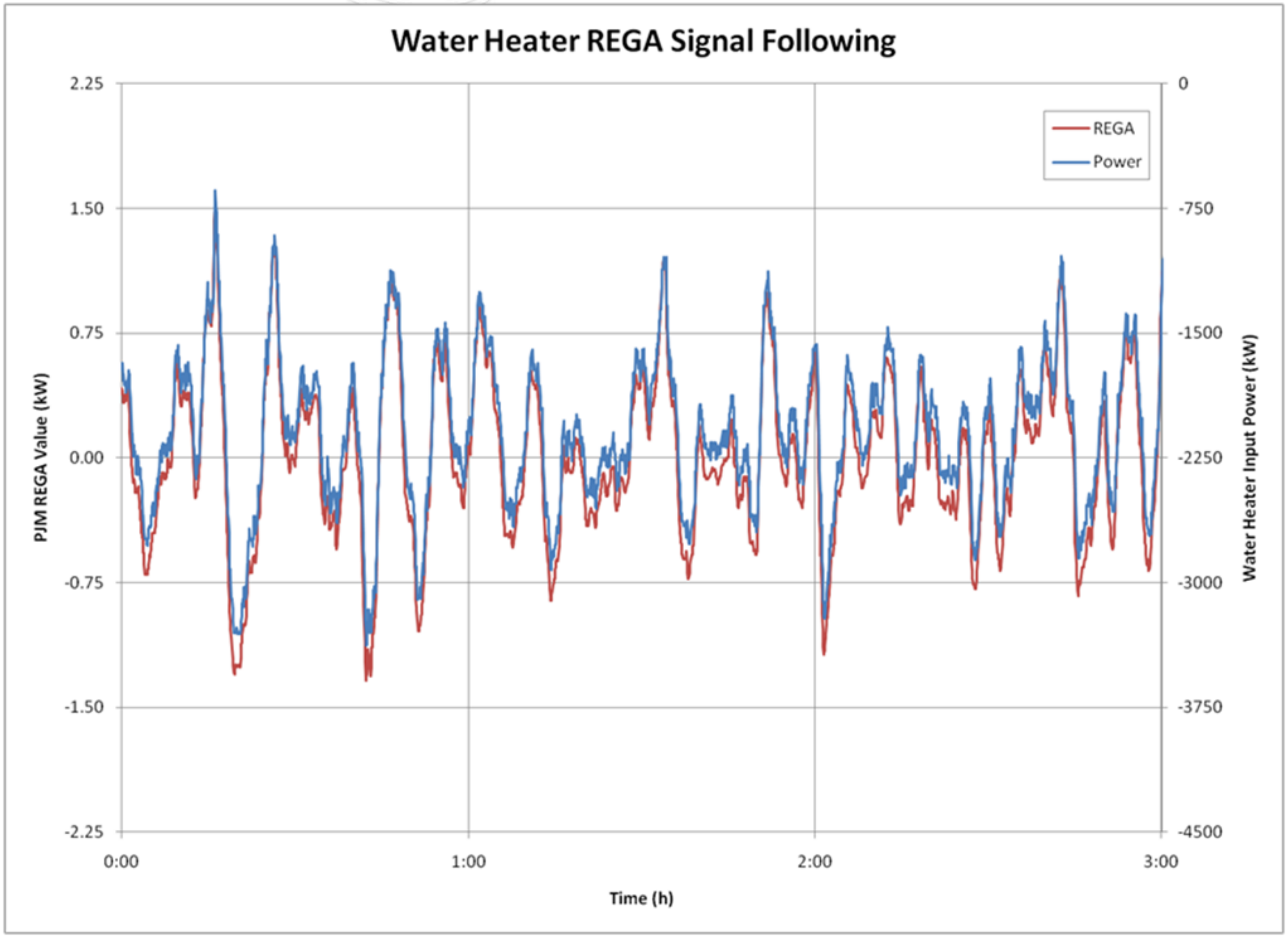
Following PJM Regulation signal



All while providing hot water to PJM Technology Center building

PJM pilot water heater -- January 14, 2011; Midnight to 3:00 a.m.

- PJM Frequency Regulation Signal
- Water heater power consumption +/- 2.25 Kw base point



Market Opportunities

Market	Performance Requirements	Size	Value
Regulation	Full raise/lower within 5 minutes and hold for 5 minutes; new requirements for fast-response "pay for performance" market clearing process (coming 2012)	1% of forecasted peak load ~600 – 1,500 MW; 2010 average, 893 MW	2010, $18/MW-h
Synchronous Reserves	Respond within 10 minutes for a duration of 30 mintues	1,246 MW, average	2010, $10.55/MW-h
Economic Energy	N/A	Average real time load, 76,035 MW; System peak, +158 GW	Average, $47.65/MWh

2) Use of EV as Grid Storage

Session 2.1
Kempton

Demonstration: Plugin EVs for Frequency Regulation

Willett Kempton
College of Earth, Ocean, and Environment
Department of Electrical and Computer Engineering
Center for Carbon-free Power Integration
University of Delaware

NIST Workshop on

Power Conditioning System Architecture for Plugin Vehicle Fleets as Grid Storage

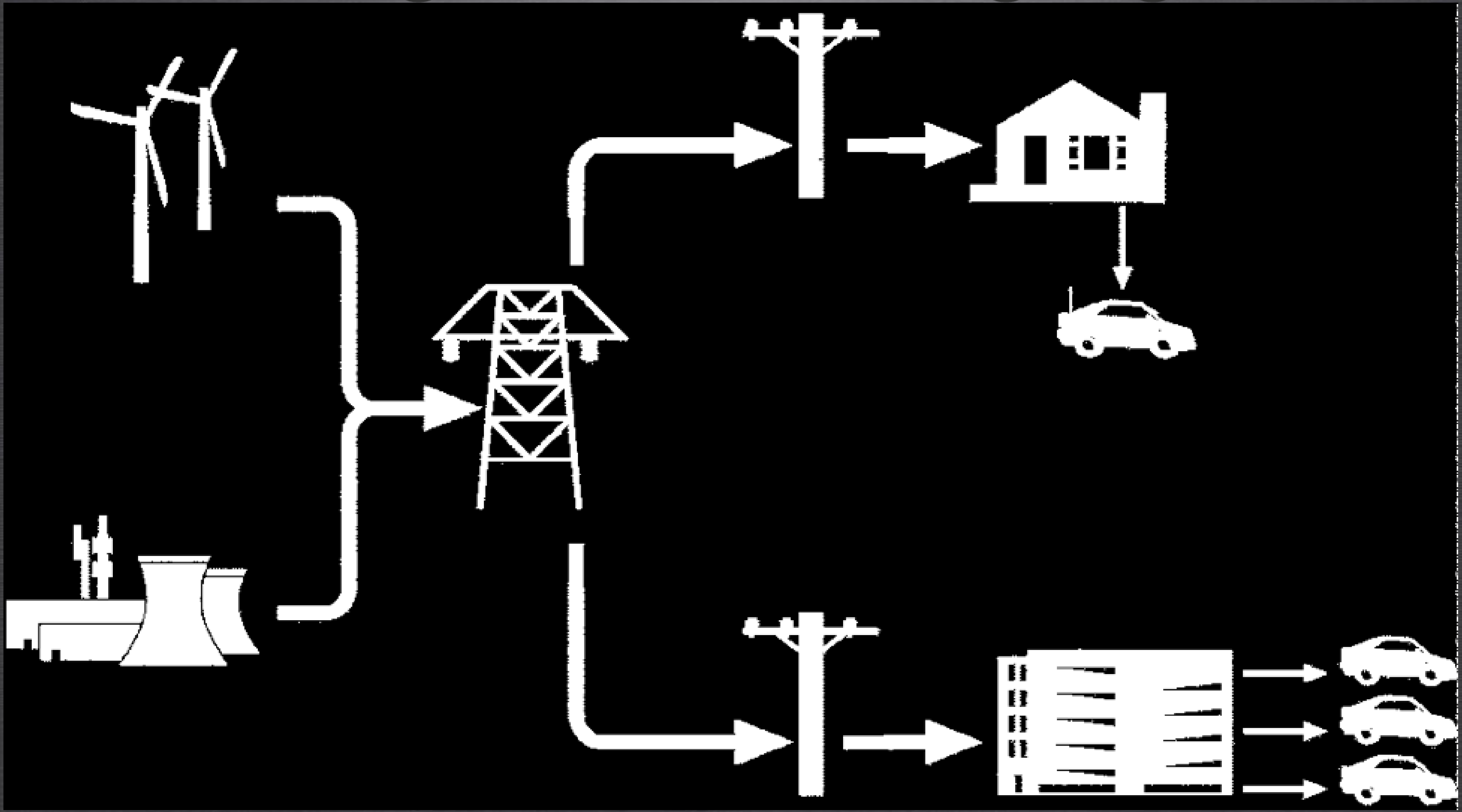
Washington, DC | 12 June 2011

Electric Vehicles

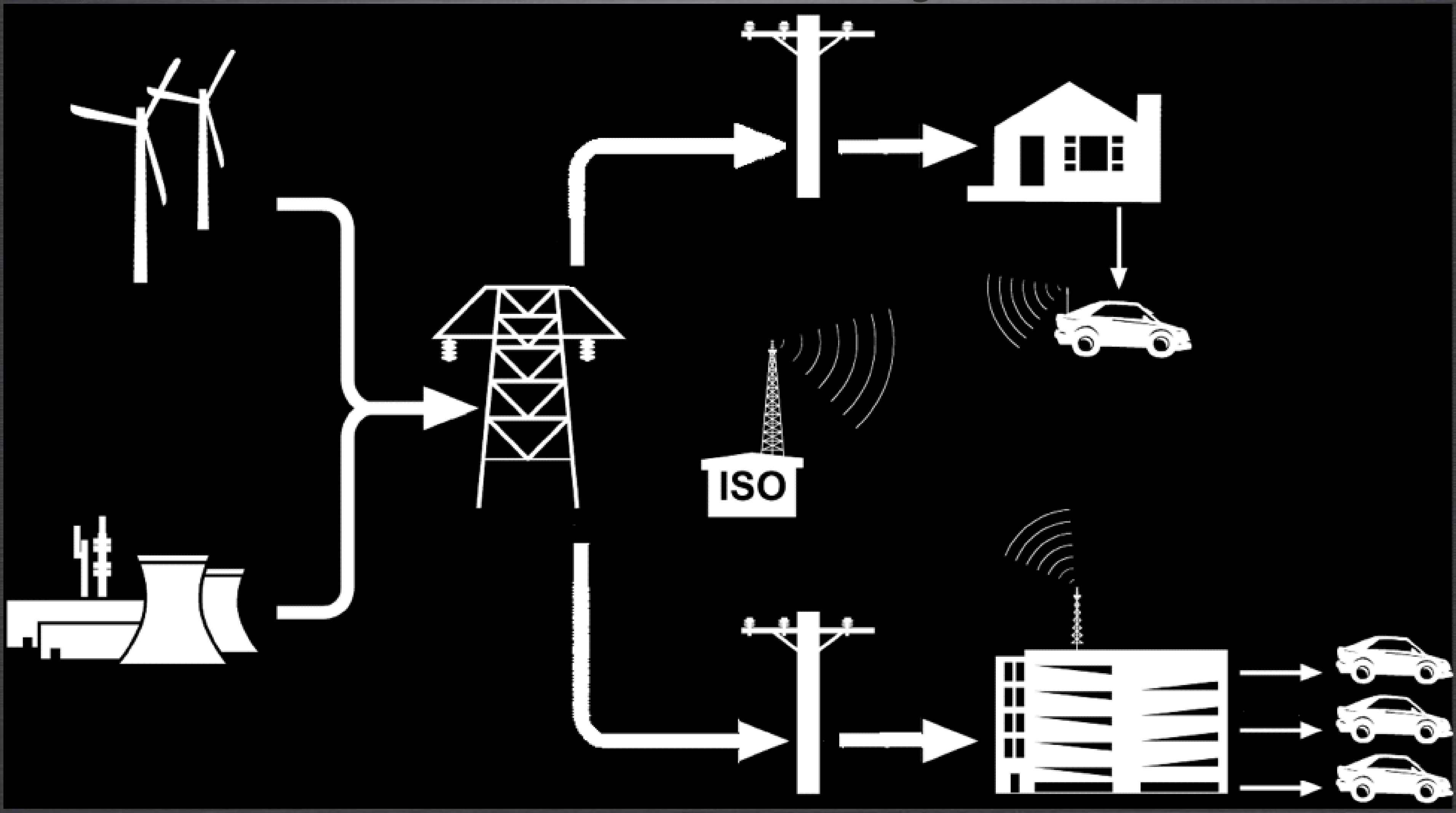
- Electricity as a fuel for the light vehicle fleet
- UD addition: Vehicle to Grid power (V2G), reverse flow from charging
- UD research: Create the **Grid Integrated Vehicle** (GIV), then operate, permit, and test it
- How does electricity as a fuel change the electric system?

The Grid-Integrated Vehicle, with Vehicle-to-Grid power

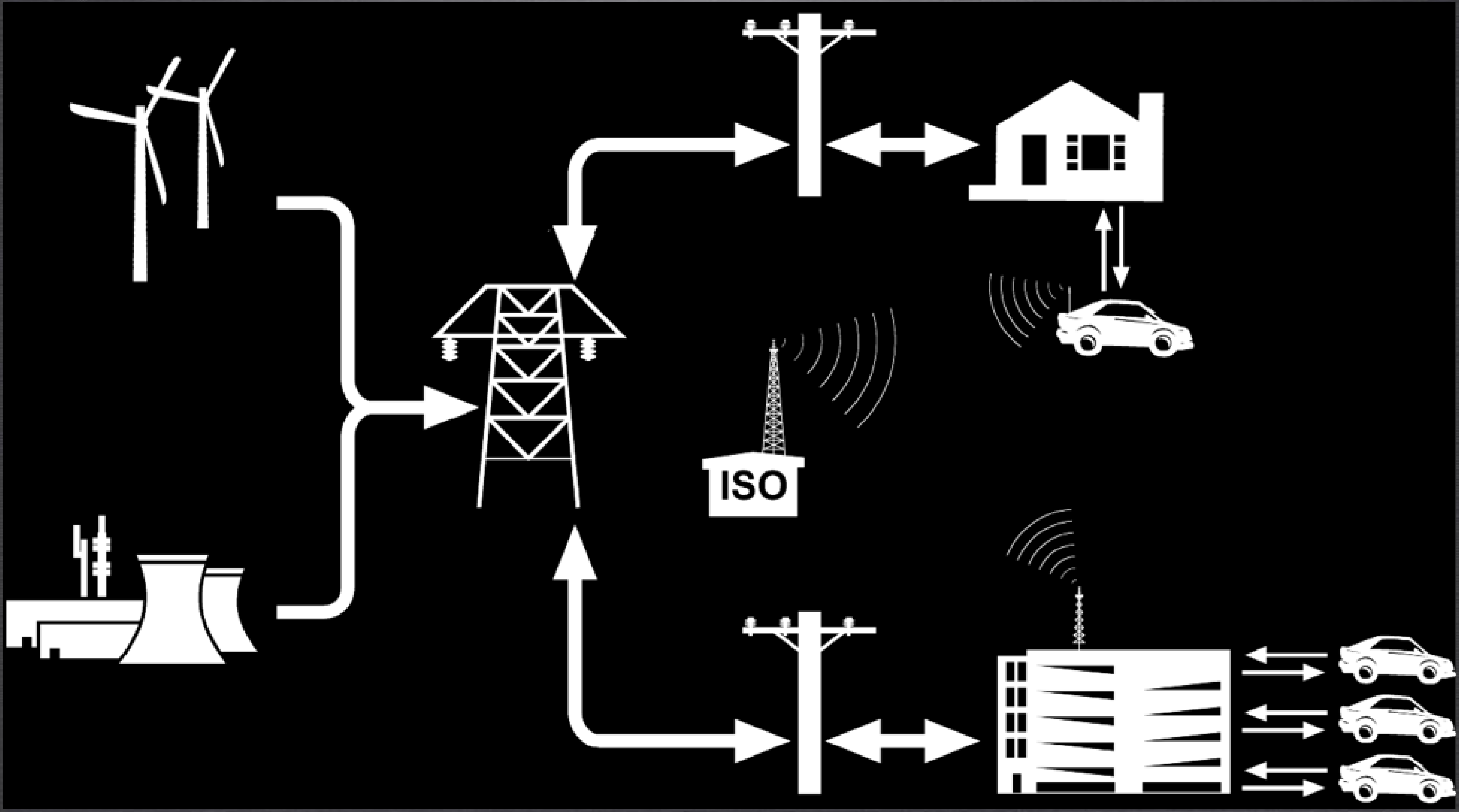
Plug-in for charging



GIV: Control by Grid



GIV+V2G: 2-Way Power Flow



Vehicle Aggregation Server

Design of Aggregator

- Provides a single, large, stable and reliable power source
- TSO does not see details of single cars, only sees aggregate
- Aggregator bids capacity in TSO market
- Dispatches dispatch requests to vehicles
- Reports actual power dispatched


pjm
UNIVERSITY OF DELAWARE
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COM 0
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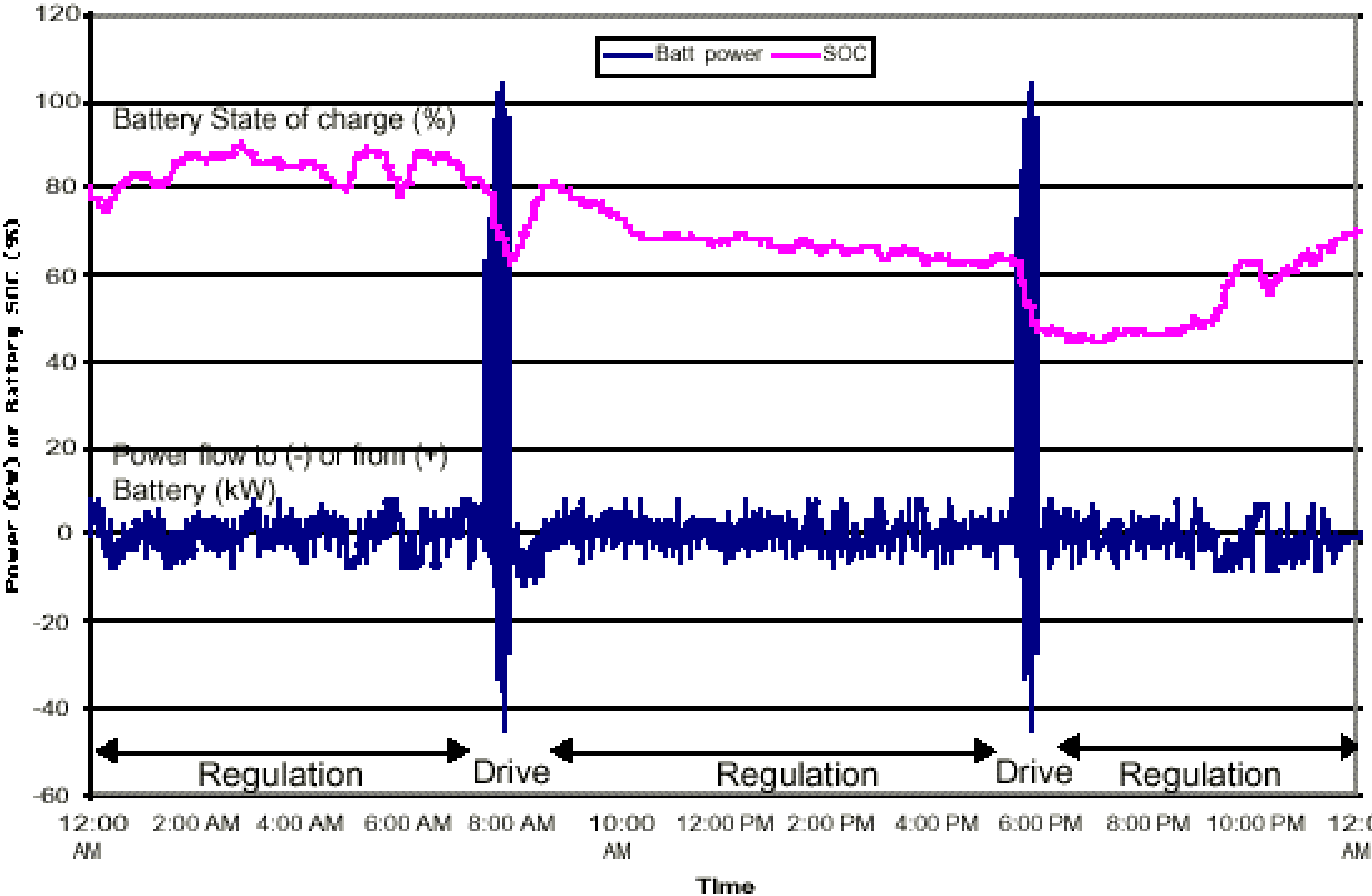
RUN
STAT
- + G
CHINOOK

Demonstration

- Seven vehicles in Delaware
- Each capable of up to 19.2 kW to or from power electronics (versus most OEMs at 3-4 kW charge only)
- When plugged in, register with server and offer capacity

Regulation, drive, regulation, drive



Results: Aggregator

Vehicle to Grid -- Coalition Server

University of Delaware

Coalition Status

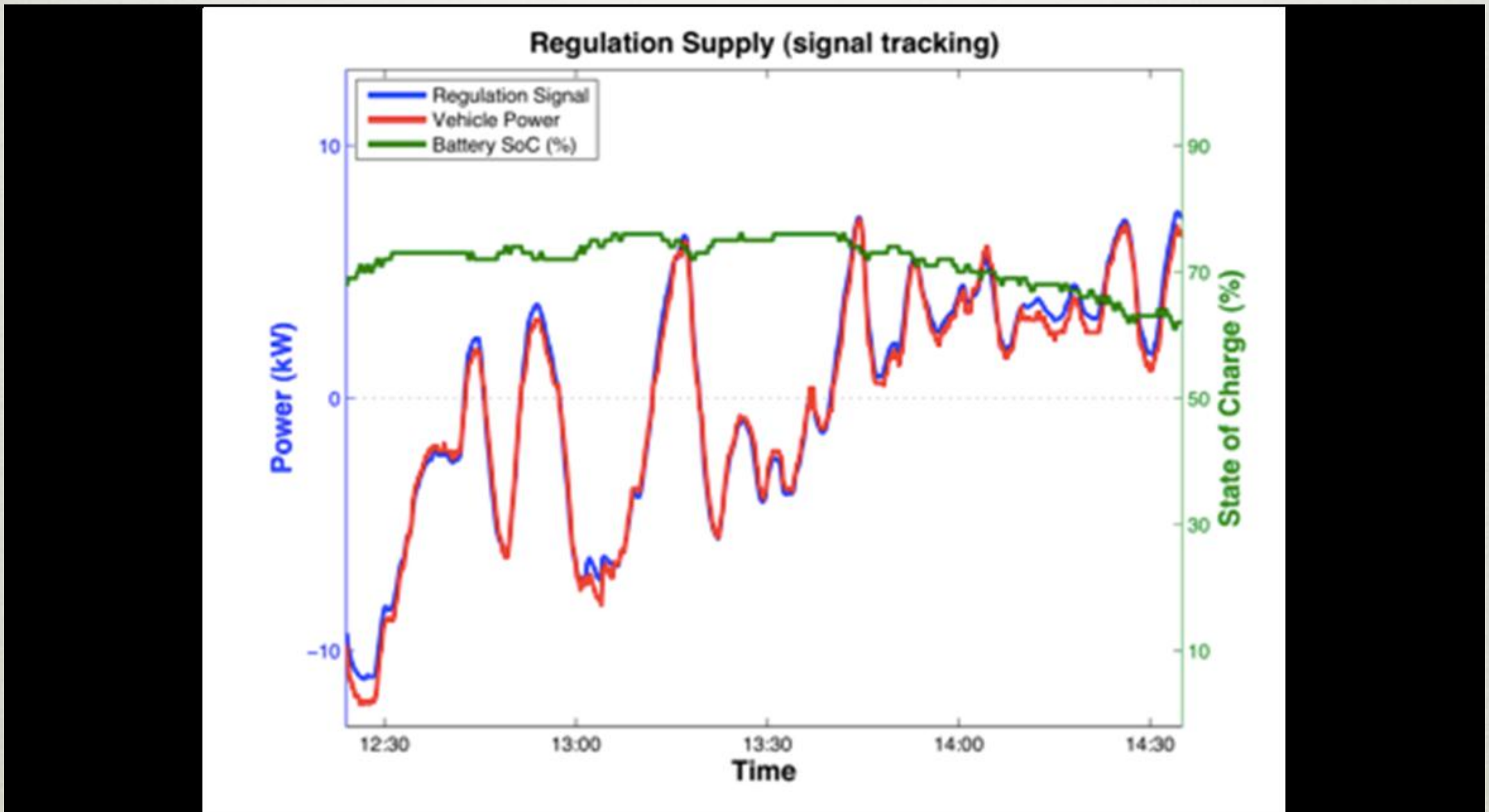
ISO	Power Capacity Up (kW)	Power Capacity Down (kW)	Power Requested (kW)	Power Provided (kW)	Energy Charge (kWh)	Energy Empty (kWh)	Number of Cars
PJM	49.37	49.37	-14.80	-15.81	104.30	35.70	4
CAL-ISO	0.00	0.00	0.00	0.00	0.00	0.00	0
Simulated-ISO	0.00	0.00	0.00	0.00	0.00	0.00	0

Hide Charts | CAL-ISO | Simulated-ISO | PJM

Individual Vehicle Status

Car Name	Power Capacity Up (kW)	Power Capacity Down (kW)	Power Requested (kW)	Power Provided (kW)	Energy Charge (kWh)	Energy Empty (kWh)	Miles	Volts (V)	Amps (A)	Monthly Credit ($)
UD-296	0.00	0.00	0.00	0.00	29.05	5.95	91.30	211	22.5	33.17
UD-170	11.23	11.23	-3.36	-3.95	12.60	22.40	39.60	234	16.9	76.31
DEState5205	10.70	10.70	-3.21	-2.05	33.25	1.75	104.50	214	9.6	21.73
DEState0000	17.36	17.36	-5.21	-5.70	31.50	3.50	99.00	248	23	24.59
UD-210	10.08	10.08	-3.02	-4.09	26.95	8.05	84.70	210	19.5	23.38

Results: Very fast response



- Power response is very close to command signal.
- Far higher fidelity than any rotating equipment.

Why do GIV and V2G make sense?

Basic GIV/V2G Math

- US car used 1 hour/ day, parked 23 h/ d
- Drive train output = 100 kW
  - Practical power via US grid = 10 - 20 kW
- Cars as significant power capacity? Compare:
  - US generation ~1000 GW, avg. load ~450 GW
  - US light vehicles: 200 million
  - At 15 kW/ vehicle: 3,000 GW
    - **Cars: 3x generation, 6x average load**

Useful energy storage?

- Storage at the low-voltage end of the distribution system
- 15 kW & 30 kWh means ~1 hr discharge thus capacity markets, not energy
- Second use of customer equipment, thus capital costs are controls
- Need to aggregate many small storage units to get utility-scale power for TSO

Capital Cost of Distributed Capacity and Storage

- Capital cost is on-board intelligence plus communications, now ~$400
- For example, an EV with 15 kW, 30 kWh
- Capacity cost: $27/ kW
- Storage cost: $13/ kWh

Why high-power plug

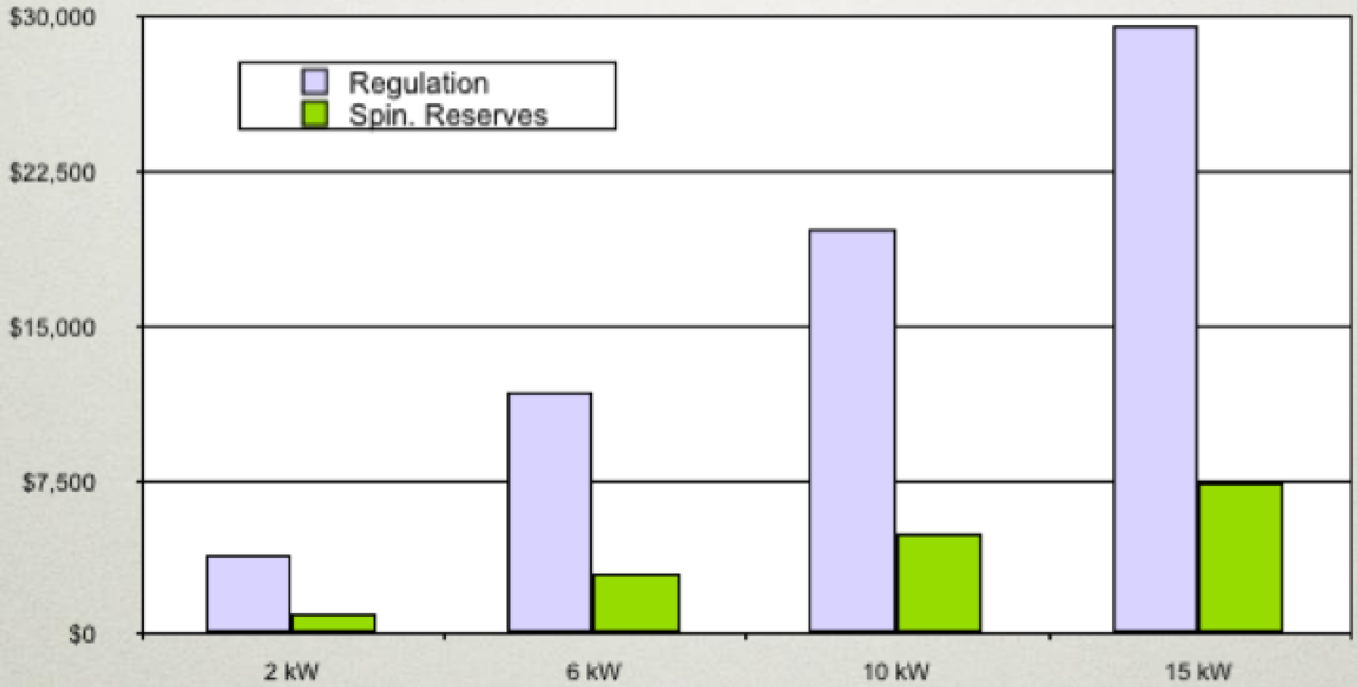
- Should be 12 - 20 kW, not 2-6 kW
- Should be 208 or 240 VAC, not 110 V
- User convenience: last minute charge or roadside recharge @a mile-a-minute
- Capacity markets: Value of grid service proportional to kW
- Renewables planning: High penetration renewables needs high capacity per car

Power for recharge: Consumer value > Cost

Charge Time	GV Class	EV Class	Incremental device cost	Strategy for charger engineering
10 hours	$0	$0	(base)	110 VAC 12 A charger on board
5 hours	$4,720	$971	$600	208/240 VAC and larger components in charger for 4 kW
1 hour	$5,900	$7,626	-$800	Use drive train to charge, 19 kW
10 min.	$6,490	$11,093	$50,000	Station DC charger at 150 kW

Value per Vehicle

10 –Year Present Value V2G Revenue Potential



Assumptions: 80% availability, Reg. $40/ MW-h, Spin. $10/ MW-h, 7% discount rate, example calculations

Sequence of Markets

- High-value markets, are ancillary services (A/ S)
  - Frequency regulation
  - Spinning reserves

Sequence of Markets

- Later -- larger markets, lower value per kW
  - Defer upgrades to distribution feeders, transformers
  - Peak load reduction, valley filling
  - Power factor correction
  - Balancing wind, reducing ramp rate
  - Shifting solar peak to load peak

Interconnect Policy

Permitted by Load-Serving Entity (local utility)

City of Newark Generator Interconnection Application -Short Form

(For Use with Generators 25 kW or Less)

An applicant (Generator Owner) makes application to the City of Newark to install and operate a generating facility of 25kW or less interconnected with the City of Newark utility system.

Section 1. Applicant Information

Name: UNIV OF DELAWARE

Mailing Address: 222 S. CHAPEL

City: NEWARK State: DE Zip Code: 19716

Facility Location (if different from above): 401 Wyoming Rd

Telephone (Daytime): Area Code 302 Number 831-4947 (Evening) Area Code 302 Number 893-2148

City of Newark Electric Account No. : 0800002497-00 Pole Number: _____

Section 2. Generator Technical Information

NEM – Net Energy Metering

Is Generator powered from a Renewable NEM Qualifying Energy Source: [X] Yes [ ] No

Type NEM Qualifying Energy Source (if applicable): [ ] Solar [ ] Wind [ ] Hydro [X] Electric Vehicle

Generator (or solar collector) Manufacturer, Model Name & Number: AC Propulsion eBox (Battery System)

Output Power Rating in kW: 120 kW

Inverter Manufacturer, Model Name & Number (if used): AC Propulsion AC-150

Rating in kW: 19.2 kW

Permitted by Load-Serving Entity (local utility)

Will a generator disconnect device, accessible to the City of Newark, be installed?: ☐ Yes ☒ No

If the Generator Owner elects not to install a manual disconnect device accessible to the City of Newark, the Generator Owner assumes all risks and consequences when a service meter must be "pulled" to disconnect the generator thereby also interrupting all utility electric service to the Customer site.

Will an automatic transfer switch be used? ☐ Yes ☒ No

Supply specifications for the transfer switch showing UL listing and "Break before Make" contacts.

Section 3. Generator/Equipment Certification

~~Generating systems that use utilize inverter technology must be compliant with IEEE 929 and Underwriters Lab. UL 1741.~~ By signing below, the Applicant certifies that the installed generating equipment meets the appropriate preceding requirement(s) and can supply documentation that confirms compliance. *

Signed (Applicant): ____________ Date: 1/8/09

* Documentation has been provided to the City certifying that the AC-150 inverter meets IEEE 1547 standards.

"meets IEEE 1547 standards"

Law to codify interconnects, net metering for V2G

SPONSOR: Sen. Simpson & Rep. Kowalko
Sen. McDowell; Rep. Hocker

DELAWARE STATE SENATE
145th GENERAL ASSEMBLY

SENATE BILL NO. 153

AN ACT TO AMEND TITLE 26 OF THE DELAWARE CODE RELATING TO CUSTOMER SITED ENERGY RESOURCES.

BE IT ENACTED BY THE GENERAL ASSEMBLY OF THE STATE OF DELAWARE (Two-thirds of all members elected to each house thereof concurring therein):

Section 1. Amend §1001, Title 26 of the Delaware Code by adding two new definitions reading as follows, and renumbering existing definitions alphabetically.

"(1) 'Aggregator' means any person or entity who contracts with an electric distribution company, electric supplier or PJM Interconnection (or its successor) to provide energy services, which facilitate battery storage systems for grid-integrated electric vehicles and related technologies.

(14) 'Grid-Integrated Electric Vehicle' means a battery-run motor vehicle that has the ability for two-way power flow between the vehicle and the electric grid and the communications hardware and software that allow for the external control of battery charging and discharging by an electric distribution company, electric supplier, PJM Interconnection, or an aggregator."

Define:

Aggregator

Grid-integrated electric vehicle

law to codify interconnects

Section 2. Amend §1014, Title 26 of the Delaware Code by adding a new subsection to read as follows:

(g) A retail electric customer having on its premises one or more grid-integrated electric vehicles shall be credited in kilowatt-hours (kWh) for energy discharged to the grid from the vehicle's battery at the same kWh rate that customer pays to charge the battery from the grid, as defined in (e)(1) of this section. For electric customers with time of use rates, the kWh rate for charging and discharging shall be the rate in effect when charging or discharging occurs. Excess kWh credits shall be handled in the same manner as net metering as described in (e)(1) of this section. To qualify under this subsection, the grid-integrated electric vehicle must meet the requirements in (d)(1)a., (d)(1)b. and (d)(4) of this section. Connection and metering of grid integrated vehicles shall be subject to the rules and regulations found in (e)(2), (e)(3), and (e)(4) of this section.

Net metering for V2G

Net is at rate at time of use

Interconnection requirements, etc same as distributed renewables

Patents

Patents

- Patent Applications, 2007-2010:
  - U.S. Patent Application Publication Nos. 2007/ 0282495 A1 "System and Method for Assessing Vehicle-to-Grid (V2G) Integration" filed May 2007 (UD; Kempton and Tomic)
  - U.S. Patent application publication No. "Hierarchical Priority and Control Algorithms for the Grid-Integrated Vehicle", filed March 2009, (UD; Kempton)
  - Three US and PCT applications in 2010, Electric Vehicle Station Equipment for Grid-Integrated Vehicles; Electric Vehicle Equipment for Grid-Integrated Vehicles; Aggregator Server for Grid-Integrated Vehicles. Filed Sept 2010 (UD; Kempton and co-inventors)
- Signed licenses for VSL and Aggregator, in license negotiations for EVSE and more VSLs

So even when your car is parked, it is working earning money for you


120

Net Results of DOE-Funded R&D

- Fully-functioning GIV with real-time dispatch by grid operator
  - Concept proven and running
  - Licenses to commercial entities
  - Manufacturing vehicles & components
- Use J1772 for signaling without pinout change
- Laws passed; rule agreement
- Measured value of EV attributes and range needs

Thanks to our sponsors

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ELECTRICITY DELIVERY &
ENERGY RELIABILITY

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ENERGY

Delaware
ENERGY
OFFICE

google.org

Pepco Holdings, Inc

Delaware
ECONOMIC DEVELOPMENT OFFICE

LA
DWP
Los Angeles
Department of
Water & Power

California Environmental Protection Agency
AIR RESOURCES BOARD

END

More information:

www.udel.edu/V2G

www.magicconsortium.org

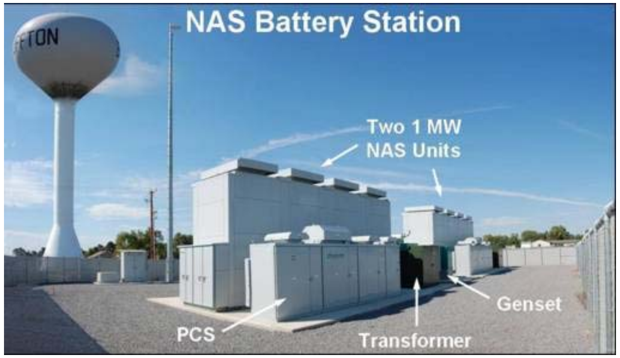
2) Use of EV as Grid Storage

Session 2.2
Weaver

Energy Storage At AEP

Community Energy Storage:

– Easiest to site
– 25-500kW



Substation Scale:

– Easier to site
– 1-10s of MW

Pumped Hydro:

– Difficult to site
– 100s of MW

Costs remain too high for single benefit value streams although they are coming down

AEP is in "learning" mode

gridSMART®
From AEP AMERICAN ELECTRIC POWER

Drivers for Energy Storage

- Peak Load Shaving / Leveling
  - T&D infrastructure project deferrals
  - Increased utilization of existing Generation
- Premium Power
  - Islanding of Load Area
  - Power Quality
- Integrating Solar / Wind Generation
  - Smoothing variability
  - Time shifting
- Energy Arbitrage
  - Charge at lower cost / Discharge at higher value
- Ancillary Services
  - Frequency regulation
  - Spinning reserve

Integrating Energy Storage to the Distribution System

- Connection & protection is relatively simple electrically
- Current IEEE 1547 Guidelines conflict with some benefits
- Traditional “cost / benefit” analysis sub-optimizes application
- Should be “visible and controllable” to Distribution operators via SCADA
- Should have “configurable” control algorithms to allow dynamic changes to meet economic / reliability benefit opportunities
- Should be “self discoverable” for automated integration
- Higher penetrations may require “market clearing”

Integrating Energy Storage

1.2 MW, 7.2 MWh Distributed Energy Storage System in Chemical Station, North Charleston

Started Operation on June 26th , 2006

AEP APPALACHIAN POWER
A unit of American Electric Power

NGK Insulators Ltd
S&C Electric Co.
DOE / SANDIA

gridSMART
From AEP AMERICAN ELECTRIC POWER

CES – Virtual Station Scale Storage

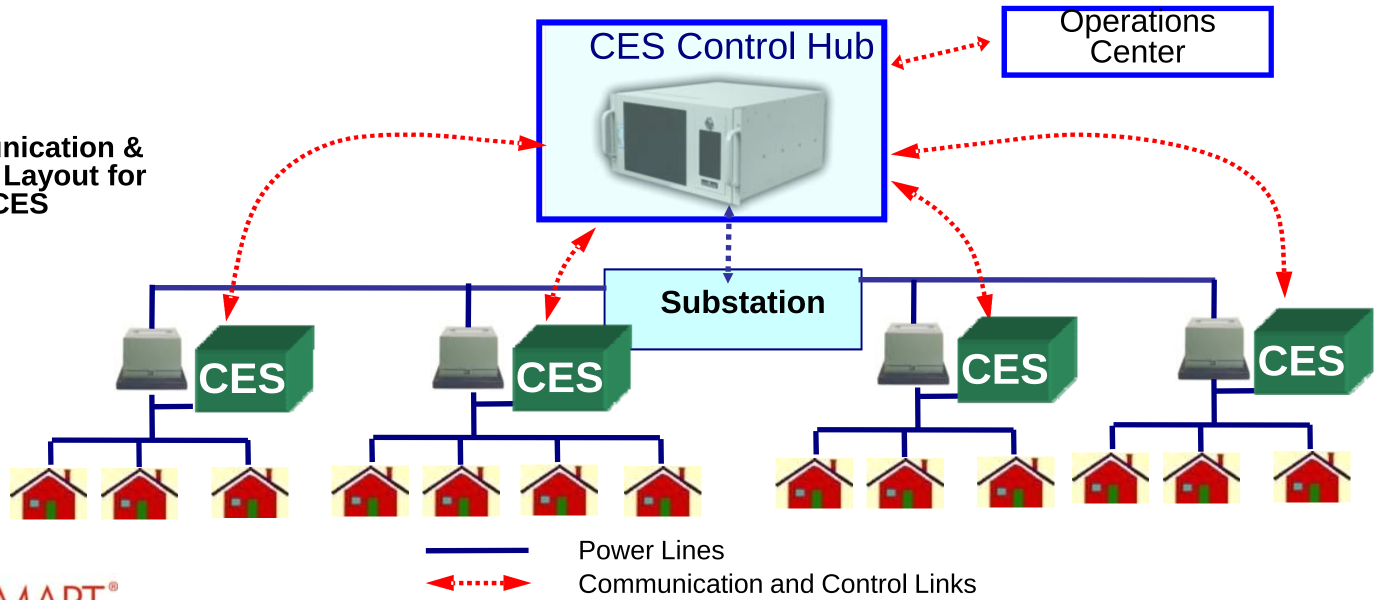
Local Benefits:

1) **Backup power**
2) **Flicker Mitigation**
3) **Renewable Integration**

Grid Benefits:

4) Load Leveling at substation
5) Power Factor Correction
6) Ancillary services

Communication & Control Layout for CES



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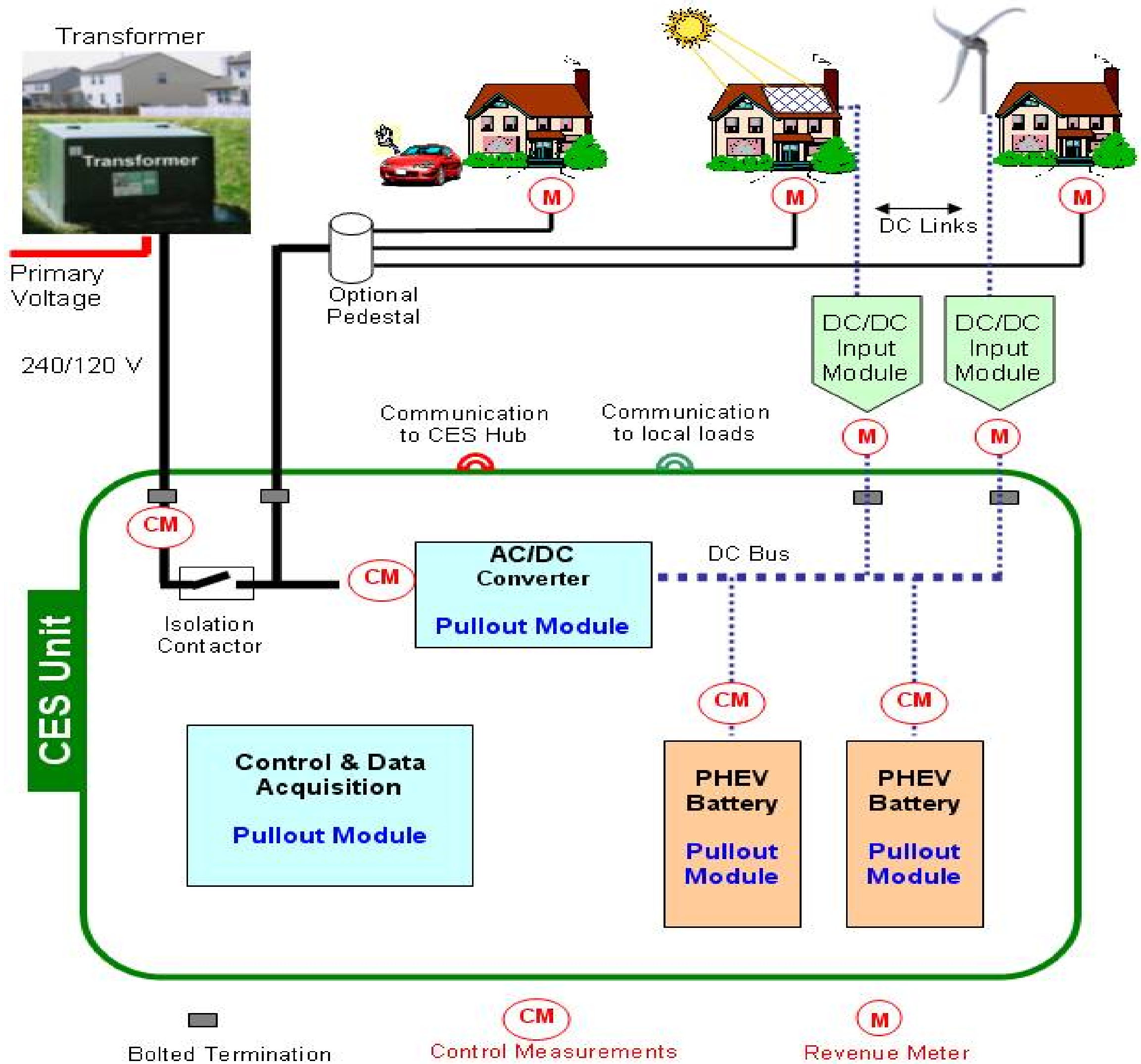
CES Layout



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From AEP AMERICAN® ELECTRIC POWER

American Electric Power Energy Storage

Questions?

Tom Weaver – AEP – tfweaver@aep.com

2) Use of EV as Grid Storage

Session 2.2
Schneider

Potential Value of Storage for Distribution Systems

Kevin Schneider Ph.D., P.E.
Pacific Northwest National Laboratory
kevin.schneider@pnl.gov
(206) 528-3351

Pacific Northwest
NATIONAL LABORATORY

Where does Distribution Energy Storage Reside?

- Substation batteries
  - MW/MWh scale batteries located within the substation fence line.
  - NAS and flow.
- Pole top or pad mounted batteries
  - kW/kWh scale batteries located near the secondary transformers.
  - NiMH and Li-Ion.
- Electric Vehicles (EVs) and Plug in Hybrid Electric Vehicles (PHEVs)
  - kW/kWh scale batteries that are in vehicle at varying locations.
  - NiMH and Li-Ion.
- Building energy storage
  - kW/kWh units where energy is stored in the form of heat.
  - Air or water.

Characteristics of Distribution Storage

- There are many forms of energy storage and not all are suitable for distribution level applications.
  - NiMH, Li-ion, NAS, and flow batteries have shown to be cost effective at various points on the distribution system.
  - Pumped hydro, flywheels, ultra-capacitors, and superconducting magnetic energy storage in general have not been shown to be cost effective at the distribution level.
- While the storage medium may vary there are some basic characteristics to energy storage:
  - A real world energy storage device will consume energy through internal losses and inverter inefficiencies.
  - Despite being located on the distribution system, there are still transmission level impacts.
  - The control algorithm for a specific energy storage device will determine what its primary function is.

Uses of Distribution Level Energy Storage

- Transmission level uses of distribution level units
  - Peak shaving at the system level
  - Congestion management at the sub-transmission level
  - Regulation services (e.g. spinning reserve and ramping services)
  - Reactive power support *
  - Defer capital upgrades
- Distribution level uses of local units
  - Peak shaving at the feeder level
  - Congestion management at the feeder level
  - Ancillary services for local intermittent renewables
  - Reactive power support *
  - Voltage control when islanded *
  - Defer capital upgrades

* Not currently supported under IEEE std. 1547

Pacific Northwest
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Control Signal

- Single input control signal
  - A simple control signal can be used to peak shave by commanding an energy storage device to discharge when load is above a set level, and to charge when load is below a set level.
  - Charge and discharge could also be controlled by a local photo voltaic system in order to mitigate the effects of cloud transients.
- Multiple input control signal
  - Single input control signals do not maximize the value of the energy storage asset.
  - In order to make a business case for the relatively high cost of energy storage the asset must be used to achieve multiple goals.
  - A multiple input control signal could be a combination of local voltage control and transmission level balancing. Local voltage control is aided by adjusting output power factor to offset local PV transients while simultaneously adjusting real output power to aid transmission level balancing.

Questions or Comments?

2) Use of EV as Grid Storage

Session 2.4
Siddall

NEXTENERGY

ask us what's next

NIST Workshop On Power Conditioning System Architectures For Plugin-Vehicle Fleets As Grid Storage

How Might A PEV Fleet Aid In Integration Of Resilient Micro-Grids?

(Storage Functions To Support Resilient Micro-Grids)

Bill Siddall, Director, NextEnergy

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What Size Is The Micro-Grid?

The size of the grid, the amount of generation and load, matters to the effectiveness of individual and aggregated Plug-in Electric Vehicles (PEVs).

Forward Operating Base Simulation

Fort Irwin, CA

60kW to 200kW

Wright-Patterson AFB

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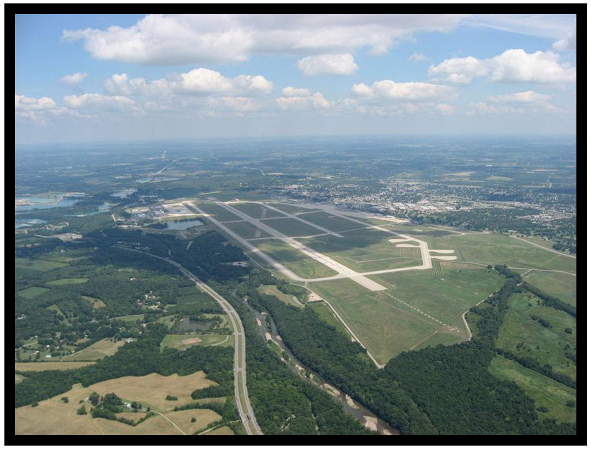

20MW to 80MW

Benefits, Maximum Market Potential, and Maximum Economic Value

Trade-Offs

#	Benefit Type	Benefit ($/kW)** Low	Benefit ($/kW)** High	Potential (MW, 10 Years) CA	Potential (MW, 10 Years) U.S.	Economy ($Million)† CA	Economy ($Million)† U.S.
1	Electric Energy Time-shift	400	700	1,445	18,417	795	10,129
2	Electric Supply Capacity	359	710	1,445	18,417	772	9,838
3	Load Following	600	1,000	2,889	36,834	2,312	29,467
4	Area Regulation	785	2,010	80	1,012	112	1,415
5	Electric Supply Reserve Capacity	57	225	636	5,986	90	844
6	Voltage Support	400		722	9,209	433	5,525
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9.2	T&D Upgrade Deferral 90th percentile††	759	1,079	77	997	71	916
10	Substation On-site Power	1,800	3,000	20	250	47	600

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Standard Assumption Values for Storage Power

Trade-Offs

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1	Electric Energy Time-shift	1 MW	500 MW	Low per ISO transaction min. (Can aggregate smaller capacity.) High = combined cycle gen.
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9.2	T&D Upgrade Deferral 90th percentile	250 kW	2 MW	Same as above.
10	Substation On-site Power	1.5 kW	5 kW	Per EPRI/DOE Substation Battery Survey.
11	Time-of-use Energy Cost Management	1 kW	1 MW	Residential to medium sized commercial/industrial users.

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Standard Assumption Values for Discharge Duration

Trade-Offs

*Hours unless indicated otherwise. Min. = minutes. Sec. = Seconds.

#	Type	Discharge Duration* Low	High	Note
1	Electric Energy Time-shift	2	8	Depends on energy price differential, storage efficiency, and storage variable operating cost.
2	Electric Supply Capacity	4	6	Peak demand hours
3	Load Following	2	4	Assume: 1 hour of discharge duration provides approximately 2 hours of load following.
4	Area Regulation	15 min.	30 min.	Based on demonstration of Beacon Flywheel.
5	Electric Supply Reserve Capacity	1	2	Allow time for generation-based reserves to come on-line.
6	Voltage Support	15 min.	1	Time needed for a) system stabilization or b) orderly load shedding.
7	Transmission Support	2 sec.	5 sec.	Per EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications.[17]
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PEV Fleet Characteristics

Organizational Control Of Fleet Designs and Operations

- Vehicle Specification: PEV Balance of Parts' Design as presented by Original Equipment Manufacturer (OEM)

- Vehicle Location: Operational requirements when PEV is not a micro-grid storage device

- Vehicle Service Time: Operational duty cycle compatibility with micro-grid duty cycle.

Micro-Grid Storage Application Recommendations

Application	Definition	Power	Duration	Response	Locaton of Storage	Use Description	Application Element
Regulation of Voltage & Frequency	second-by-second power balancing to regulate frequency	1-2% of system max	up to 5 min.	<10 sec.	Sub-Station	"Short Term" Power Quality maintenance Ideal PEV Fleet Application	Voltage Support
							Transmission Support
							Electric Service Reliability
			15 - 30 min	< 10 sec			Electric Service Power Quality
							Wind Gen. Grid Integration (short duration)
Spinning Reserve Reduction/ Load Following	Displace reserve generation asset with storage	8-12% of load	5 to 30 min.	<10 sec.	Sub-Station / Peaker Plant location		Load Following
							Area Regulation
			15 - 30 min				Electric Supply Reserve Capacity
T&D Deferral/Load Profile Management (Transmission & Distribution)	Delay investing in transmission & distribution infrastructure by storing energy for peak periods	XX% of max load	up to 12 hrs	10 to 30 min.	Sub-Station / Peaker Plant location	Distributed Load Management Some PEV Fleet Application	T&D Upgrade Deferral 50th Percentile
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			hours				Transmission Congestion Relief
Peaking Generation/ Deferral							Electric Supply Capacity
Arbitrage	Buy-low-sell-high on energy cost	depends on business case up to 12 hrs.		10 to 30 min.	Peaker Plant /Generator location		Electric Energy Time Shift
							Time of Use Energy Cost Management
			1 hr				Demand Charge Management
Diurnal or Longer Load Profile Management	Matching generation profiles of AE source to daily or longer load	realtive to % of AE sources	12 hours or longer (6-12 hrs)	30 min.	AE site location	Bulk Energy Storage No PEV Fleet Application	Renewables Capacity Firming
							Renewables Energy Time Shift
							Weind Generation Grid Integration: long duration

PEV Fleet Considerations In Support of Micro-Grids

In Summary:

- Micro-Grid Size
- PEV Design from OEMs
- Benefits Trade-Offs
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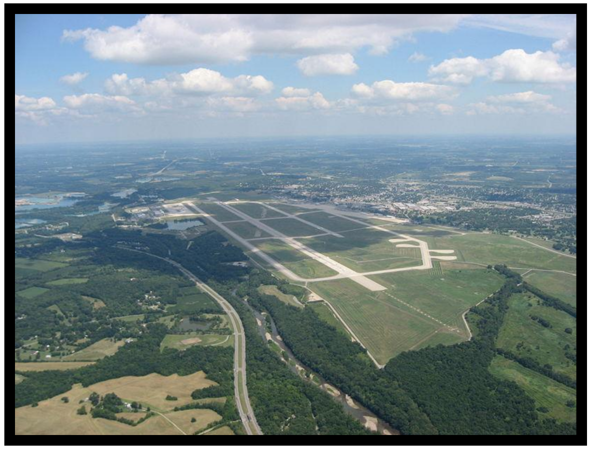

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2) Use of EV as Grid Storage

Session 2.3
Skutt

Inverter/Storage functions to Support Renewable Integration

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

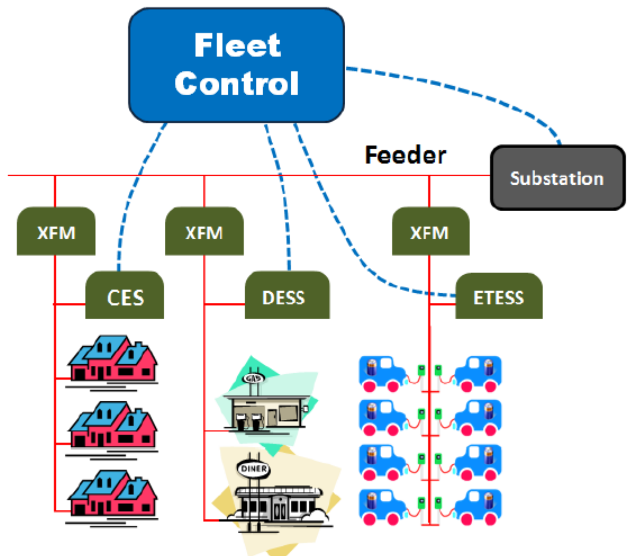
Session 2.3: How might a PEV Fleet aid in integration of distributed variable renewable generators?

Glenn Skutt

PEV Integration with Storage

ETESS is a Smart Grid Asset

AEYCH



Voltage	Phases	Power	Energy
240VAC	1ϕ	75kW	225kWh
240VAC	3ϕ	150kW	450kWh

ETESS is a Distributed Energy Storage System – an upsized Community Energy Storage unit.

ETESS units can be controlled individually and as a fleet to support the needs of the grid for peak load management, voltage (VAR) support, and frequency regulation.

ETESS can also autonomously and intelligently control and optimize the PEV loads to manage the aggregate site demand.

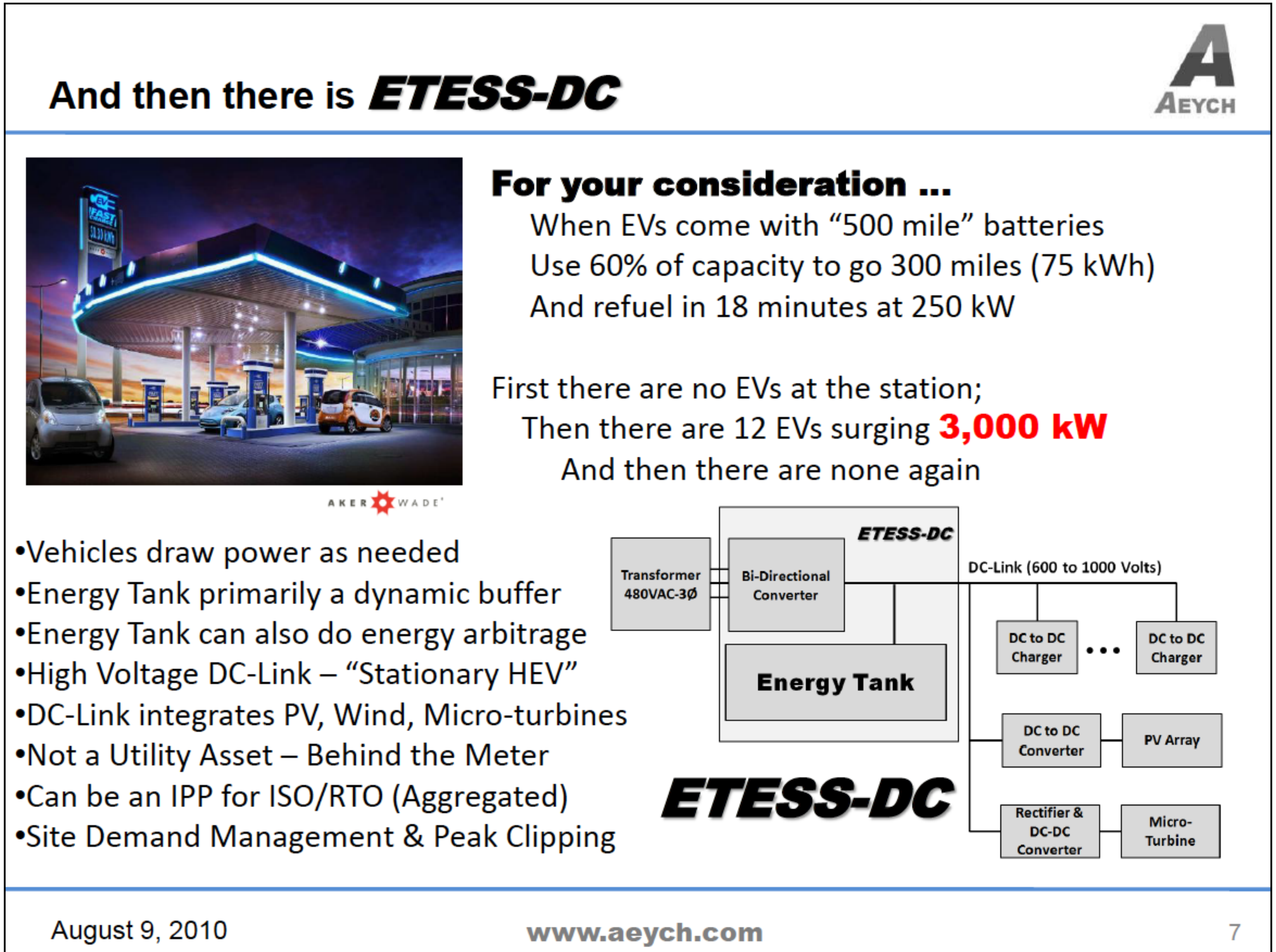
August 9, 2010 www.aeych.com 6

One vision: Distributed energy storage units controlled as a part of PEV fleet management

Requires storage system inverter control and integration with PEV activities

http://www.neny.org/download.cfm/McGlynn.pdf?AssetID=1492

PEV Rapid Charge Stations



Integration of stationary storage with the intermittent load of rapid charging PEVs.

Stationary storage managed for PEV charging AND for grid integration

http://www.neny.org/download.cfm/McGlynn.pdf?AssetID=1492

Inverter Control/Communications Development Efforts

- Standards Development:

EPRI: "PV & Storage Inverter Interactions using IEC 61850 Object Models and Capabilities"

NIST Priority Action Plan 7: "Electric Storage Interconnection Guidelines"

IEC 61850-4-720 and others

IEEE 1547.8: Draft Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies For Expanded Use of IEEE Standard 1547

- Various Demonstration Programs

Standards: Communications Functions

- The DER/ES control standardization efforts share some basic functions
- Use Case driven design
- Example: (from NIST PAP07 Use Case Document)

BROADCAST/MULTICAST REQUEST FUNCTIONS

4.1 Energy Use Cases

- 4.1.1 Use Case: Electric Vehicle Load Management
- 4.1.2 Use Case: PEV Participates in Utility Events

4.2 Utility Distribution Modeling and Analysis of ES-DER

- 4.2.1 Use Case: Distributed Energy Resource (DER) Management
- 4.2.2 Use Case: Management of DER Systems
- 4.2.3 Use Case: Secondary DA Functions – Automated Distribution Systems with Significant DER
- 4.2.4 Use Case: Short-Term DER Generation and Storage Impact Studies
- 4.2.5 Use Case: Optimal Placements of Switches, Capacitors, Regulators, and DER

4.3 Ancillary Services Functions

- 4.3.1 Use Case: Volt/Var Optimization: Energy Conservation Mode
- 4.3.2 Use Case: Emergency Override: Maximum Var Support Mode
- 4.3.3 Use Case: Static Var Mode
- 4.3.4 VAR Mode PV4: Passive Mode

NIST Smart Grid PAP07

- Examples of direct commands to an ES-DER system include:
  - Connect/disconnect from grid
  - Charge to % of capacity at specified ramp rate or for specified length of time
  - Discharge to % of capacity at specified ramp rate or for specified length of time
  - Pricing signal to provide information to an autonomous ES-DER system on which to make charging/discharging decisions.

Example: EPRI Inverter Volt-VAR Control for Energy Conservation Mode

- One example of a function being defined for Inverter functionality in a DER/ES environment
- Normal Energy Conservation Mode –utility's calculation of the most efficient and reliable VAR levels for PV inverters at specific distribution points of common coupling (PCC). Can also help compensate for local low voltage due to PEV kW loads on the circuit.
- Uses an array voltage levels and their corresponding VAR levels.
- Voltage levels range between V1 and V2 in increasing voltage values.
- Values between setpoints are interpolated to create at a piecewise linear volt/var function.
- The corresponding VAR levels define the percent of Qmax (ranging between -100% and +100%) being requested for the voltage level.

Volt/Var Function (cont.)

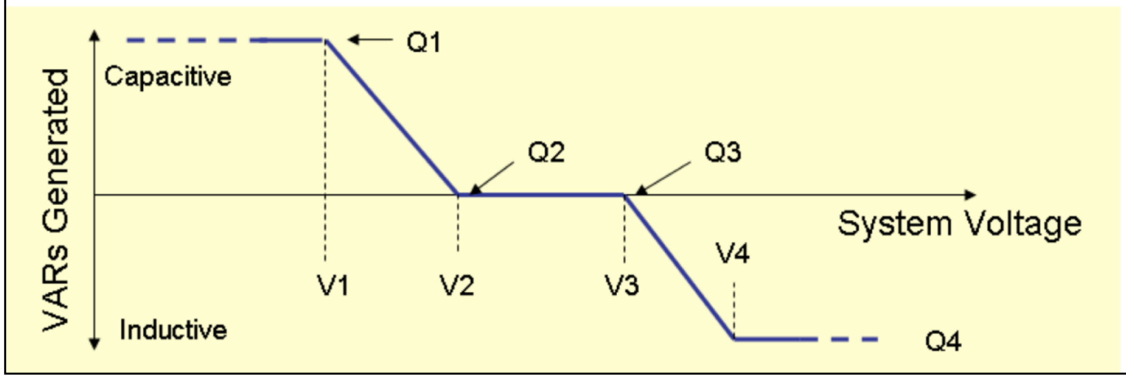
- An example of volt/var settings for this mode.
- VAR value between V_{min} and V1 is assumed the same as for V1 (Q_{max} in this example).
- Same is true for the VAR value between V4 and V_{max} ($-Q_{max}$ in this example).

Mode PV1 – Normal Energy Conservation Mode

Example Settings

Voltage Array		VAR Array (%)	
V1	115	Q1	100
V2	118	Q2	0
V3	122	Q3	0
V4	126	Q4	-100

VAR Ramp Rate Limit – fastest allowed change in VAR output in response to either power or voltage changes	50 [%/second]
Randomization Interval – time window over which mode or setting changes are to be made effective	60 seconds



Example: Request Real Power (Charge or Discharge Storage)

The utility/ESP or the Customer EMS takes the following actions:

1. (Optional) Request status of PV/Storage system: Request a pre-defined set of the status information, including the status values, the quality flag, and the timestamp of the status (see Function PC6 for details of status points).
2. Issue command to request real power (charge/discharge) setpoint for the storage system:
   a. Command **to adjust the real power charge/discharge setpoint for the storage system**
   b. Requested **ramp time for the PV/storage system** to move from the current setpoint to the new setpoint (optional – if not included, then use previously established default ramp rate)
   c. Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately, (optional – if not included, then default time window for this function will be used)
   d. Timeout period, after which the PV/Storage system will revert to its default status (optional – if not included, then default timeout period for this function will be used)
   e. Storage charge from grid setting (yes/no)
3. Receive response to the command:
   a. Successful (plus actual real power setpoint)
   b. Rejected (plus reason)

General List of Inverter/Storage Functions for PEV/DER Integration

Top Level Functions:

- Scheduled charge/discharge and advanced scheduling
- Volt VAR Control
- Watt/Frequency control
- Energy Arbitrage
- Renewables integration
- Harmonic Cancellation
- Voltage Sag Ride-Through

Implementation level:

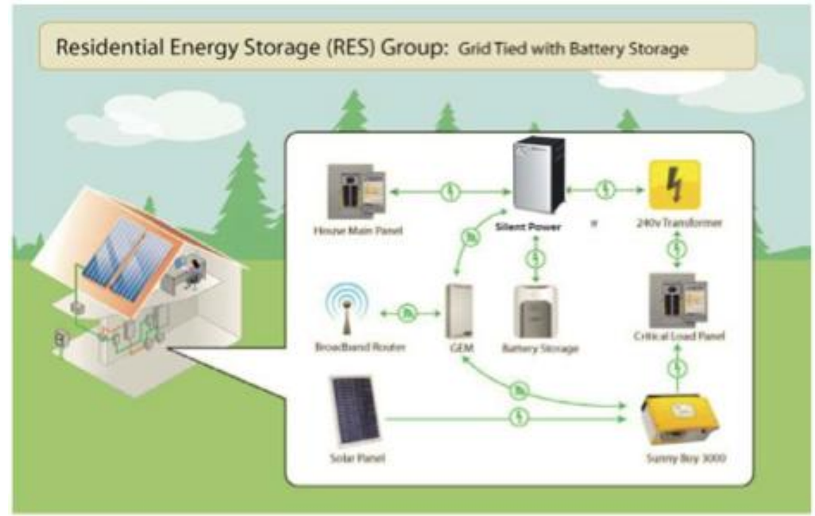
- Sense Voltage and Frequency
- Sense time rate of change of voltage and frequency
- Determine actual +/- real/reactive power output
- Determine maximum available +/- real/reactive power available
- Change to any given combination of available +/- real/reactive power
- Report nameplate information
- Report current state of V, f, P, Q, P/Q available

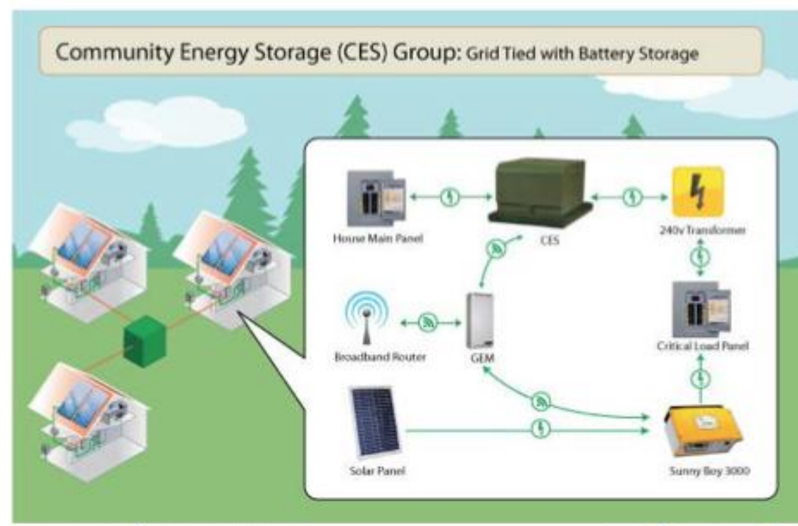
High level functions of converters or systems that control converters :

- Implement P/f schedule, i.e. P(f)
- Implement Q/V schedule i.e. Q(V)
- Implement +/- P activity as function of price information
- Provide maximum available +/- P/Q on demand subject to limits (available P/Q, V/f limits, machine limits)

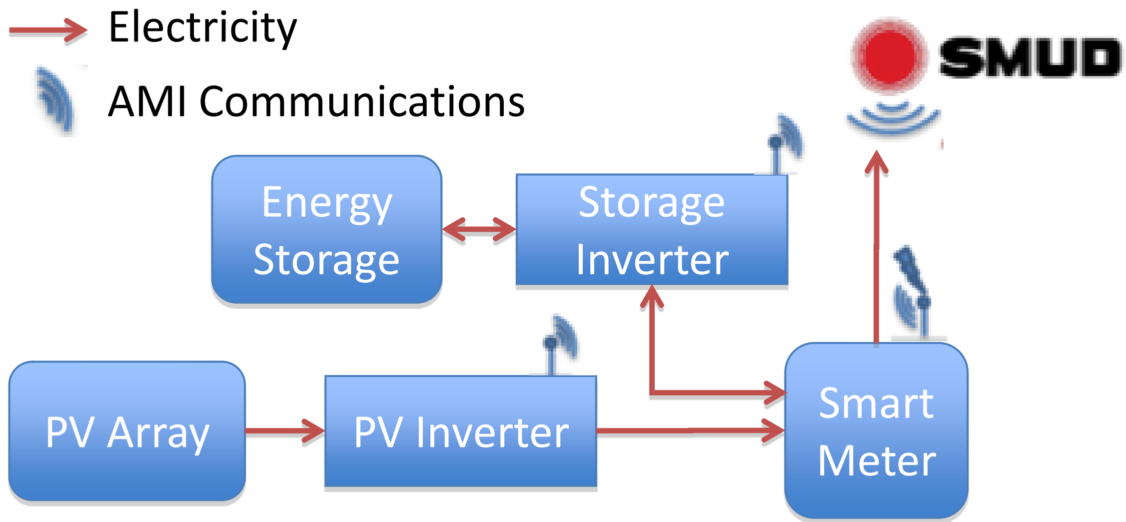
Demonstration Example: Sacramento High Penetration Solar Demonstration Project

- Control group of 25 homes with PV
  - RES Group – 15 units
    - UL listed units
    - 10kWpeak/8.8 kWh Li-ion batteries
  - CES Group – 3 units
    - Connected to secondary of 50 kVA pad mounted transformers serving 9-12 homes
    - 30 kW/30 kWh Li-ion batteries
- Utility/Customer portals monitor PV, storage, customer load
- Sending price signals to affect changes in customer usage
- Quantifying costs and benefits of this storage deployment to gain insights to broader application for SMUD





SMUD Demo Inverter Functionality



- Inverter Communications
  - Demonstrate Inverter Monitoring via AMI communication from smart meter to inverter
  - Demonstrate receiving data, querying for faults, sending control signals
  - Utilized as actively controlled contributors versus passive devices on the grid
- Functions include
  - <u>firming of PV output</u> through active regulation of energy storage inverter to compensate for fluctuations in PV output
  - scheduled charge and recharge for load shifting

Summary

- Plenty of opportunity for inverters to interact with PEV and other DER deployments
- Emerging standards for inverter control
- Inverters are generally underutilized relative to the functionality they can provide
- Combination of storage with PEV charging will be important for high PEV use levels

2) Use of EV as Grid Storage

Session 2.5
Nichols

Impact of grid storage functions on battery degradation

NIST Workshop

PCS Architectures for PEV Fleets as Grid storage

06/13/2011

Agenda

- Introduction
- Energy storage Grid applications
- Duty cycles
- Degradation modes
- Sample power applications
- closing

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Grid Storage Applications- Energy

- **Energy**
  - Hours
  - Peak shifting
  - Wind integration
  - PV integration

Grid Storage Applications - high power applications

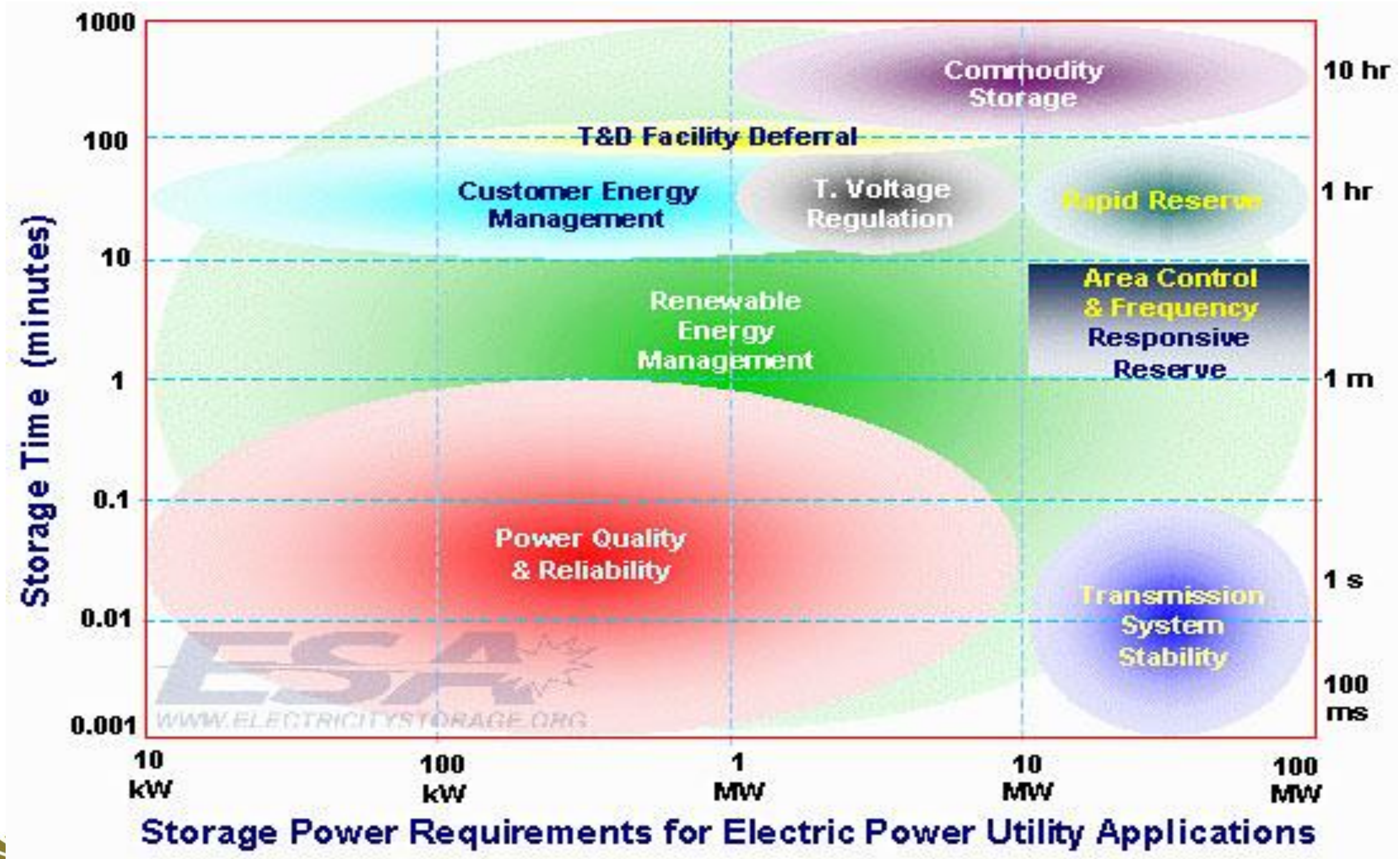
- **Seconds to minutes**
- **Frequency Regulation**
- **Wind integration**
- **PV integration**
- **Microgrid integration**
- **Power quality solution**
- **Synthetic system inertia**
- **Synthetic System primary frequency control**
- **Black start**

Energy Storage Attributes for These Applications

- **Energy rating**
- **Power rating**
  - charge
  - discharge
- **Cycling capability**
  - Useful depth of discharge
- **Energy efficiency**
- **Self-discharge characteristic**
- **Storage**
- **Calendar life**
- **Cycle life**

Energy Storage Applications-Time & Size Range

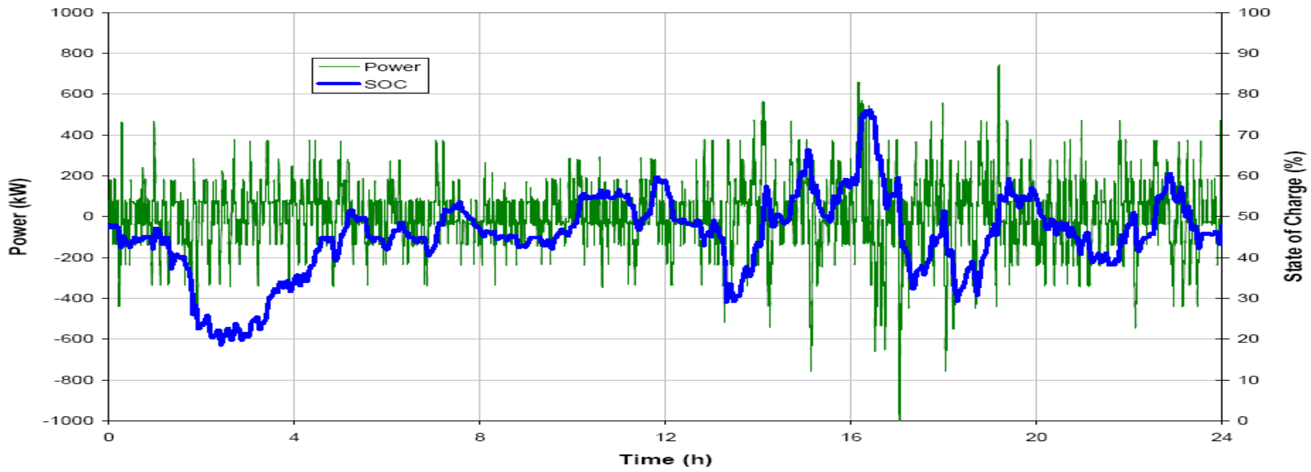
ESA (Electricity Storage Association), provides a map of applications



Data from Sandia Report 2002-1314

Example: Frequency Regulation

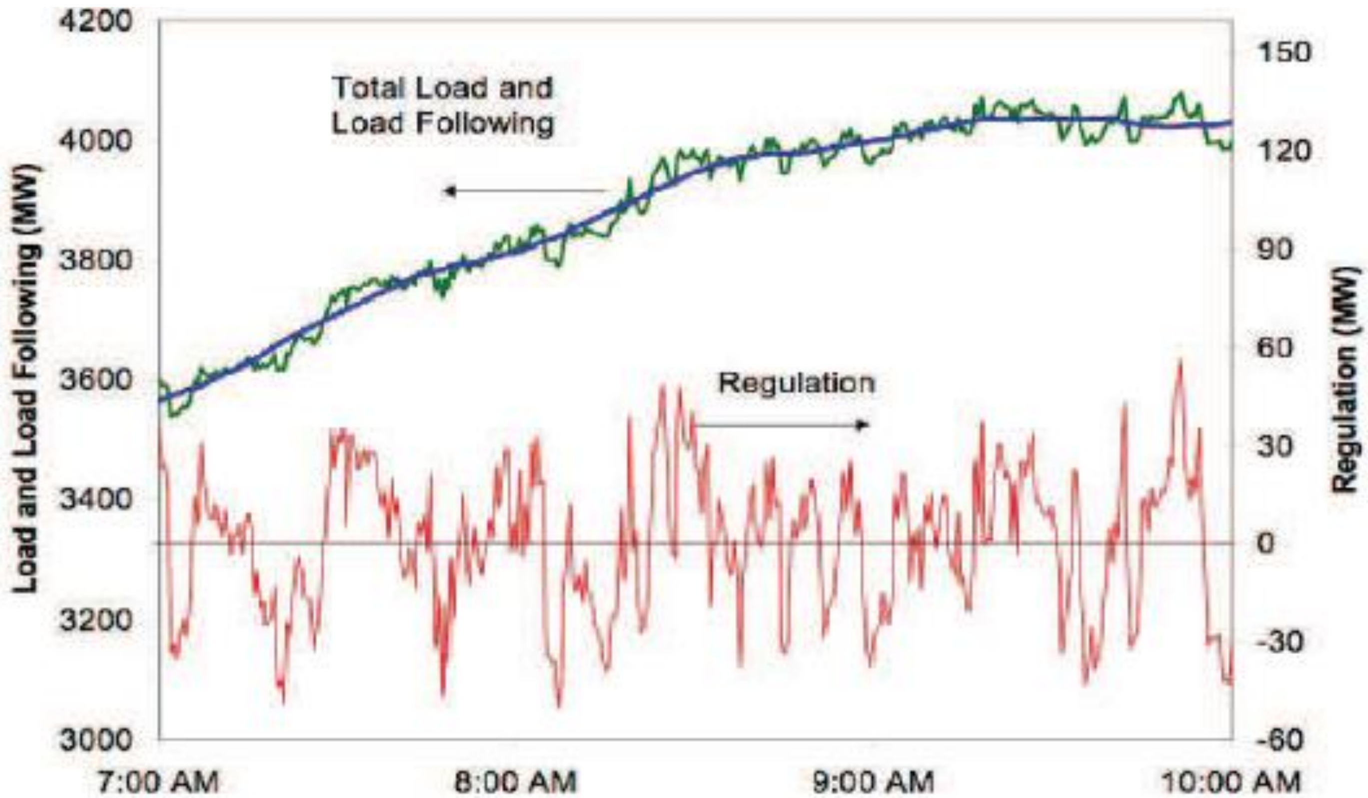
Typical 24 hour Profile



In two Years of Operation in PJM ISO

- **Performed over 250,000 small cycles and charged or discharged over 3,300 MWhr**
- **Less than two percent energy capacity degradation and no significant power capacity degradation**
- **Expected to maintain rated power and energy capacity for over twenty years without battery replacements or upgrades**

Grid Stability is maintained through the balancing of load and supply



Regulation is near zero-energy service compensation for minute-to-minute fluctuations in total system load and uncontrolled generation

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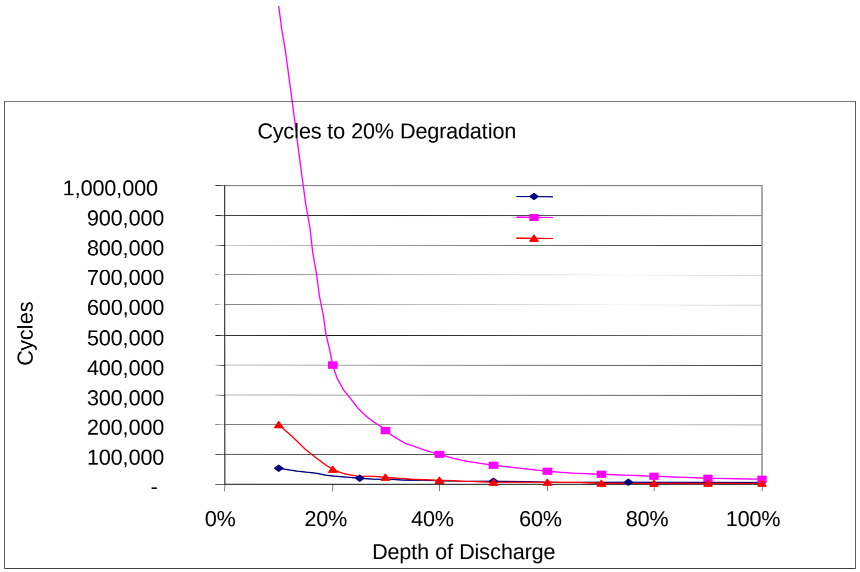
Battery technologies have different life characteristics dependent on DOD and number of cycles

- **At 100% depth-of-discharge, one technology provides 3-6 times more cycle life than others**
- **At low depth-of-discharge cycles, over 1 million cycles and up to 100X more life than others Li-Ion**



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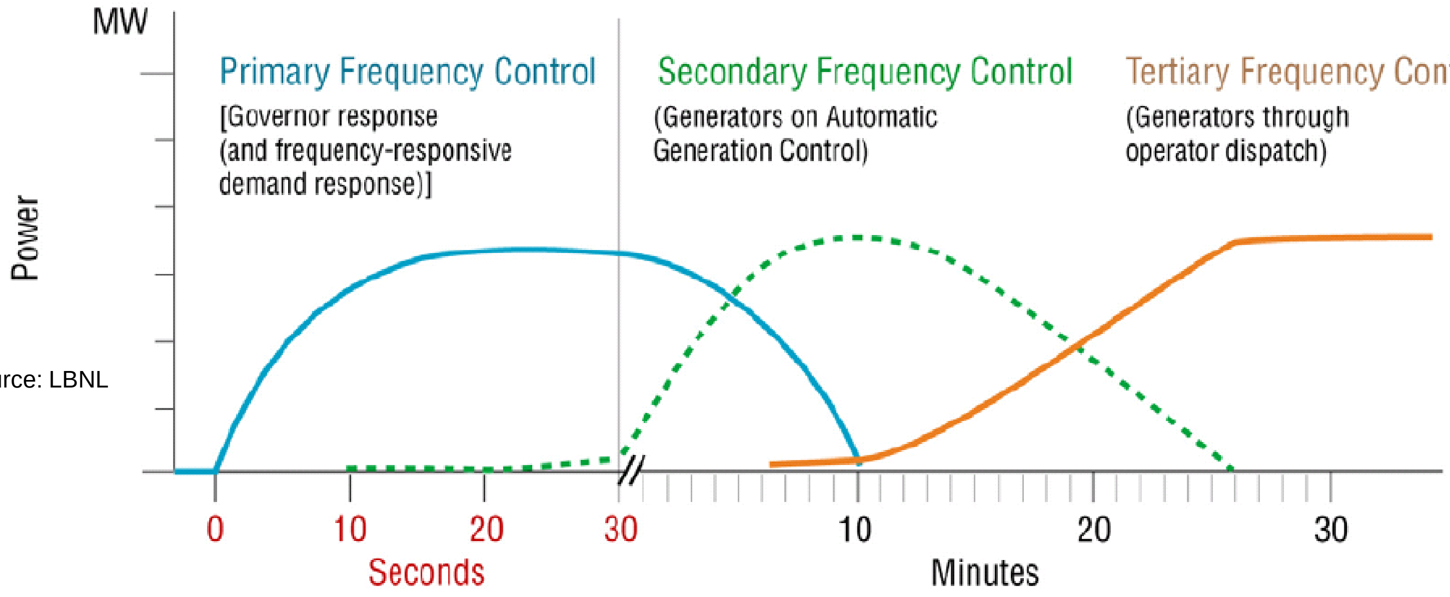
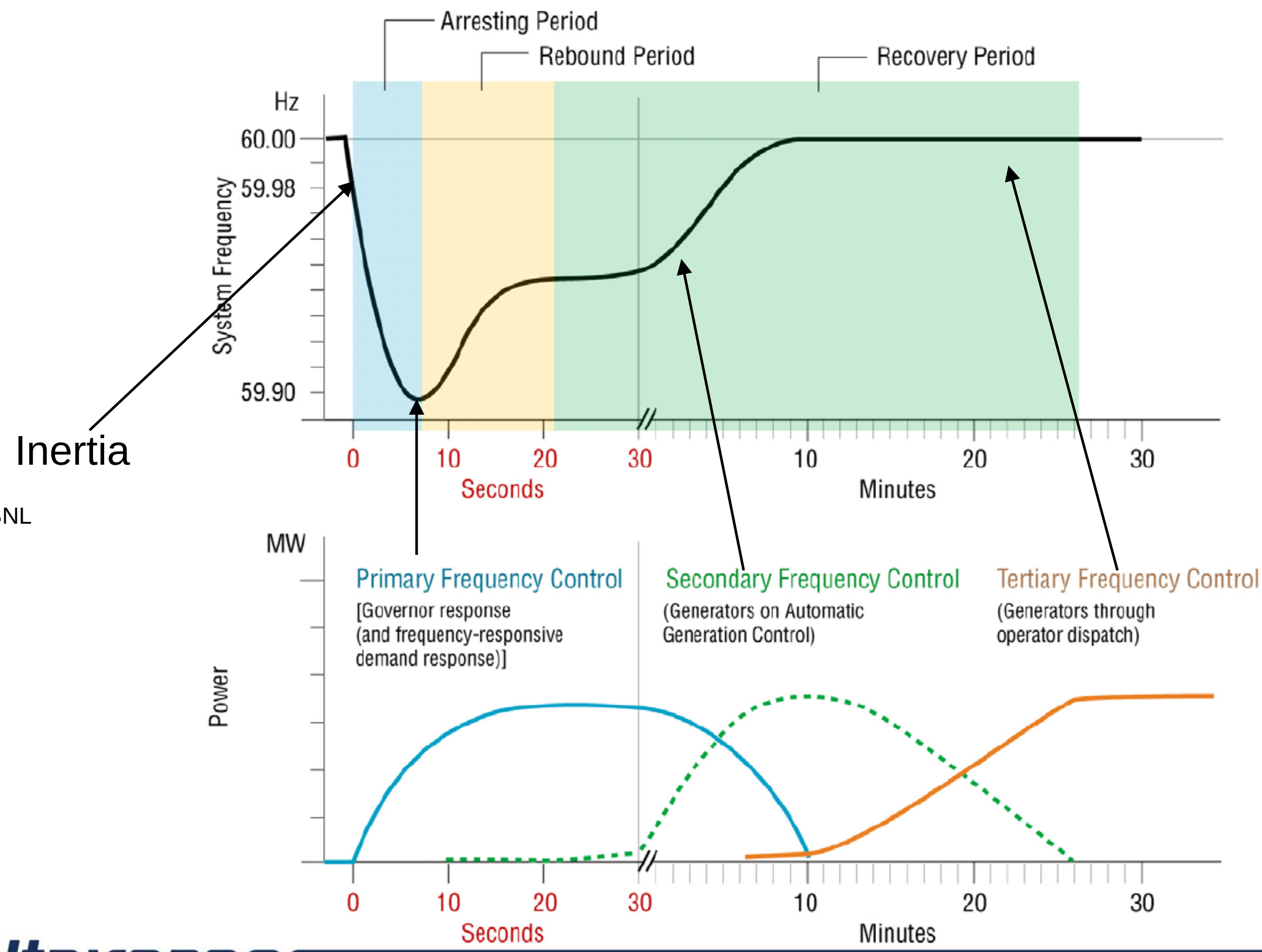
Types of Frequency Control by Timeframe



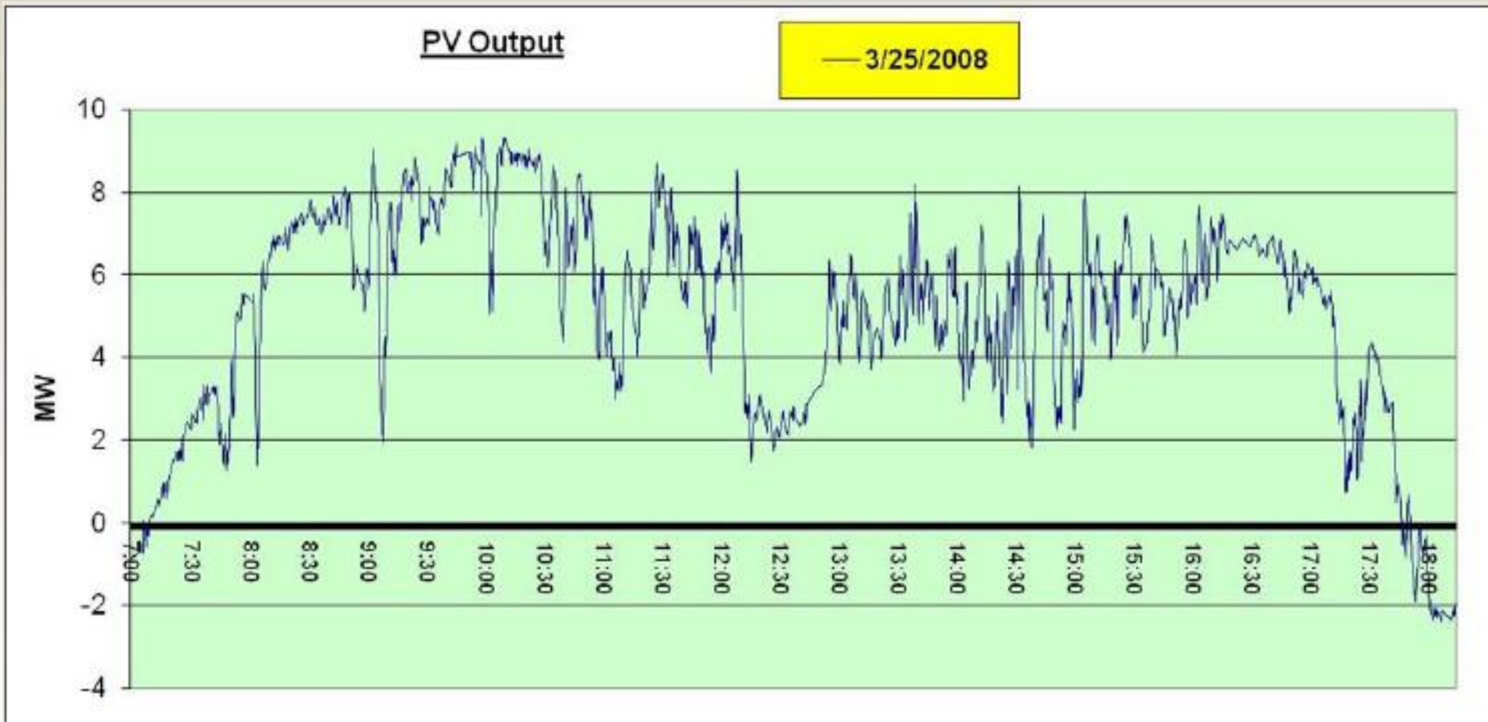
Source: LBNL

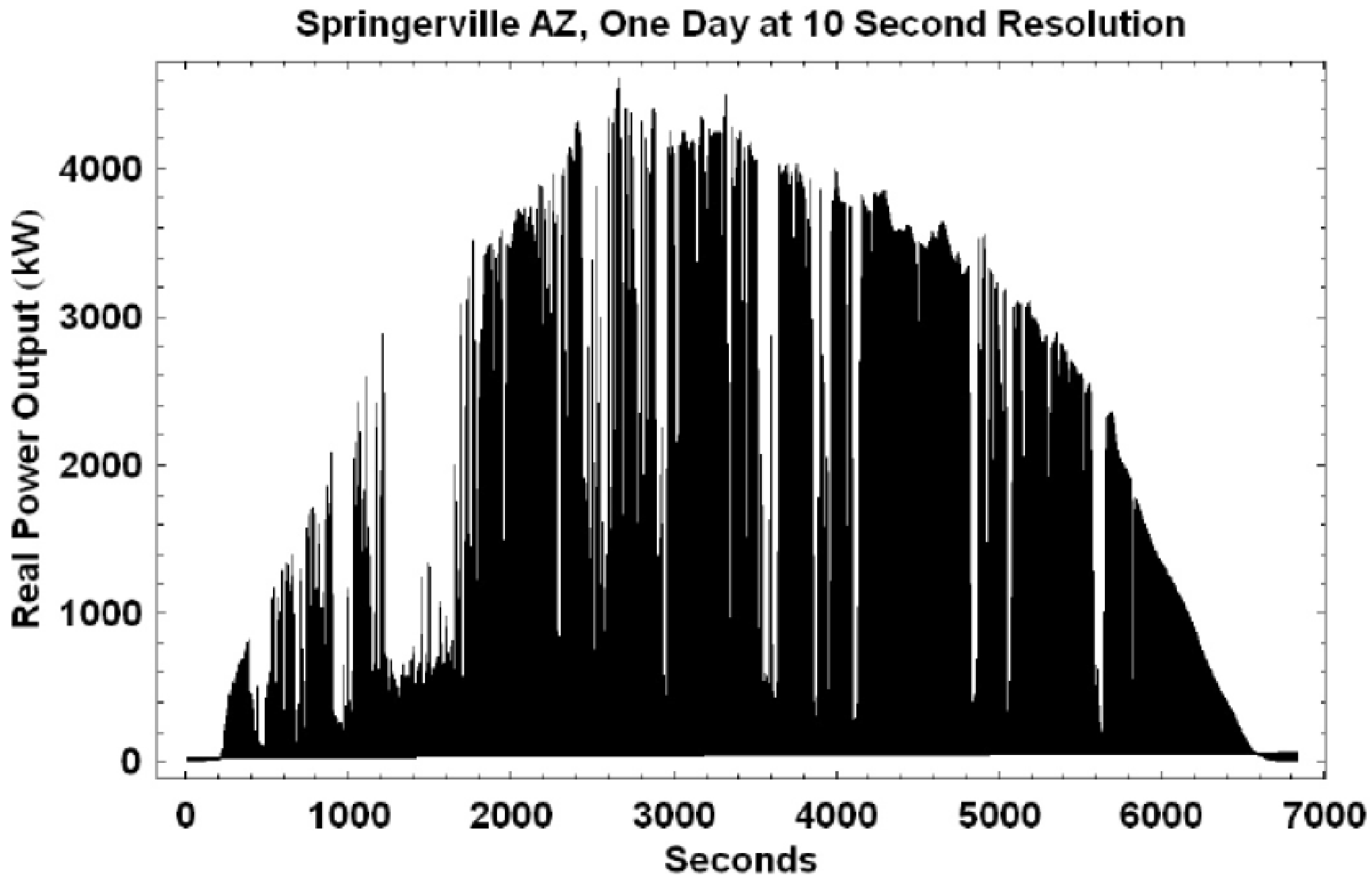
Actions of Frequency Control in a Loss of Generation Incident

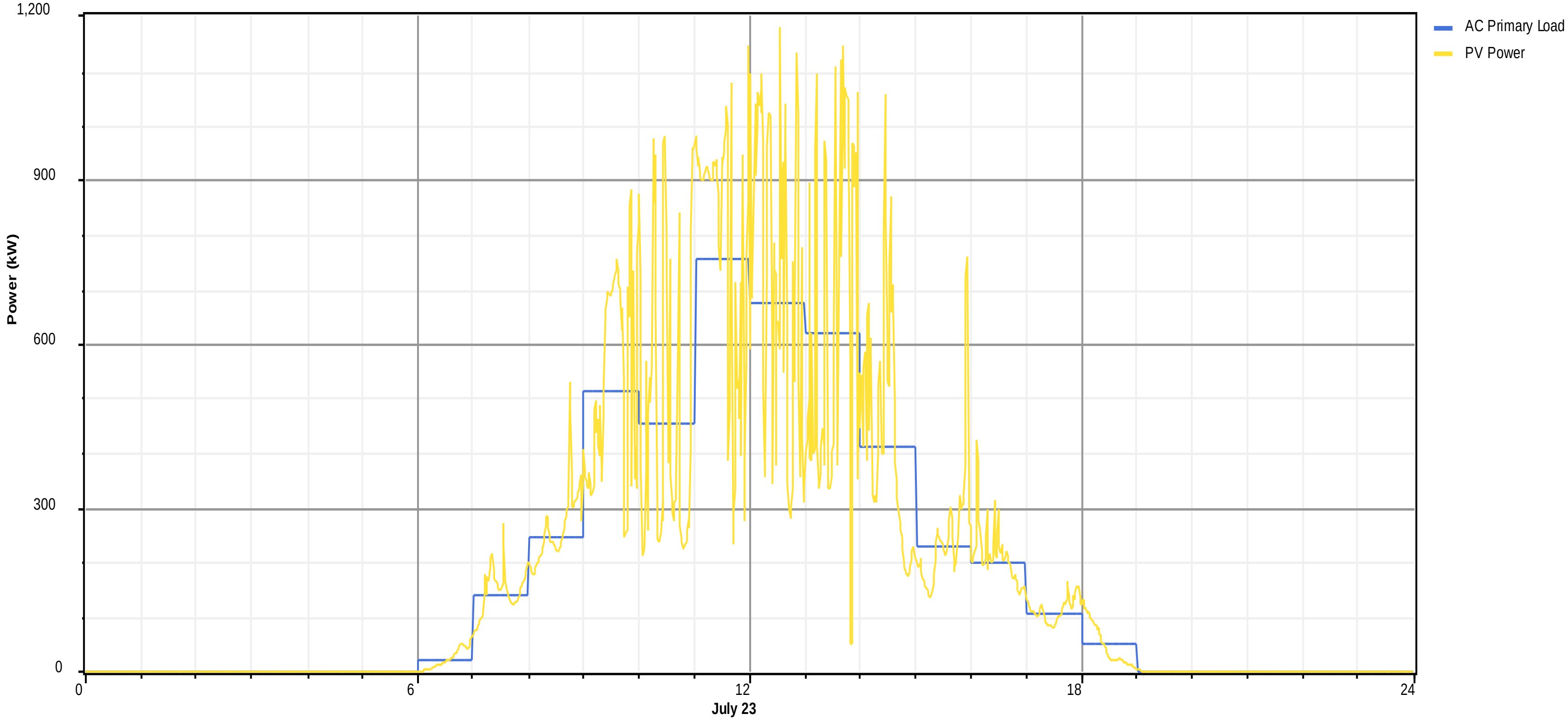


Source: LBNL

PV plant output on a partly-cloudy day (10-second sample)




Springerville AZ, One Day at 10 Second Resolution
Real Power Output (kW)
0
1000
2000
3000
4000
0
1000
2000
3000
4000
5000
6000
7000
Seconds



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SAND2008-0946 P , Printed February 2008

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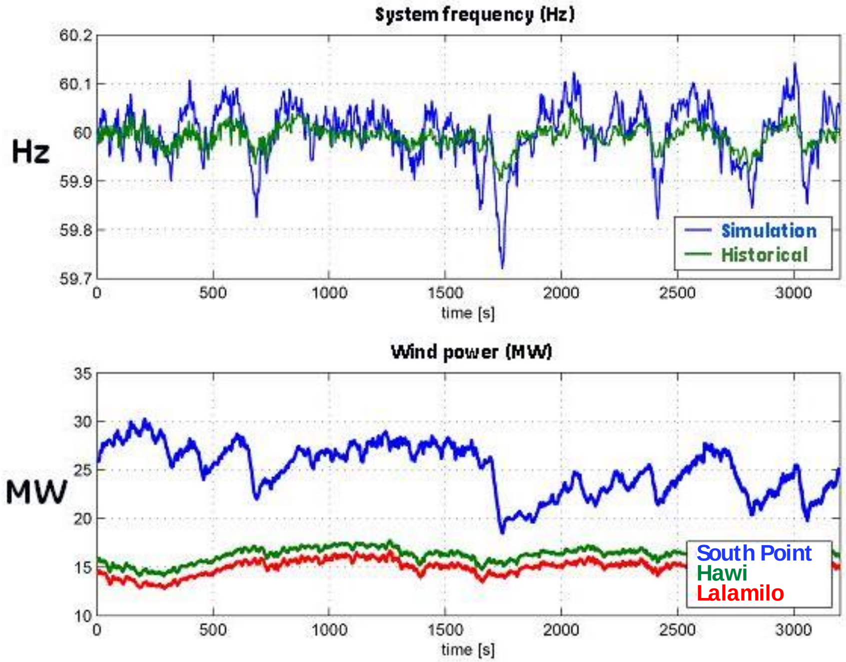

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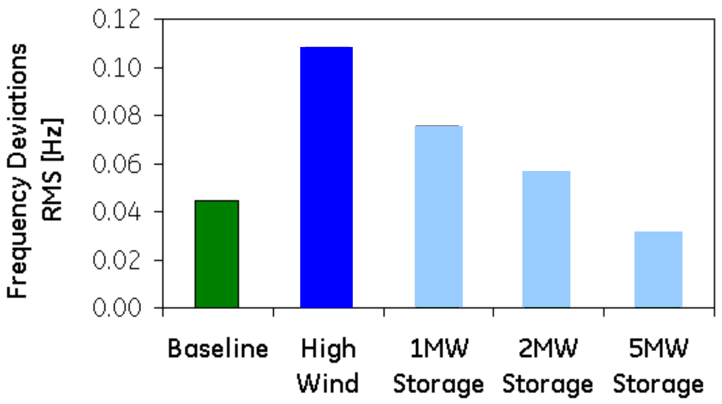

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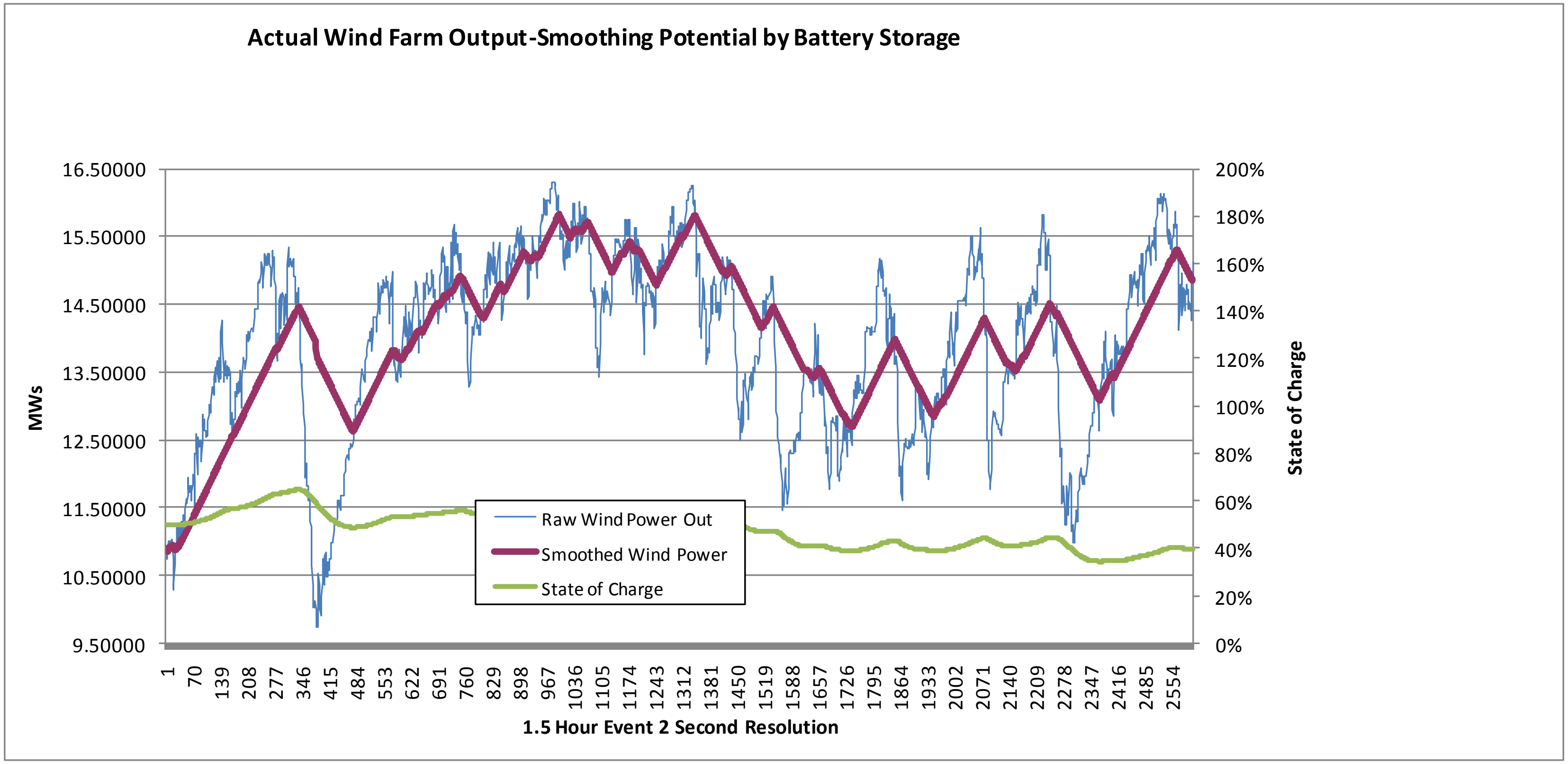
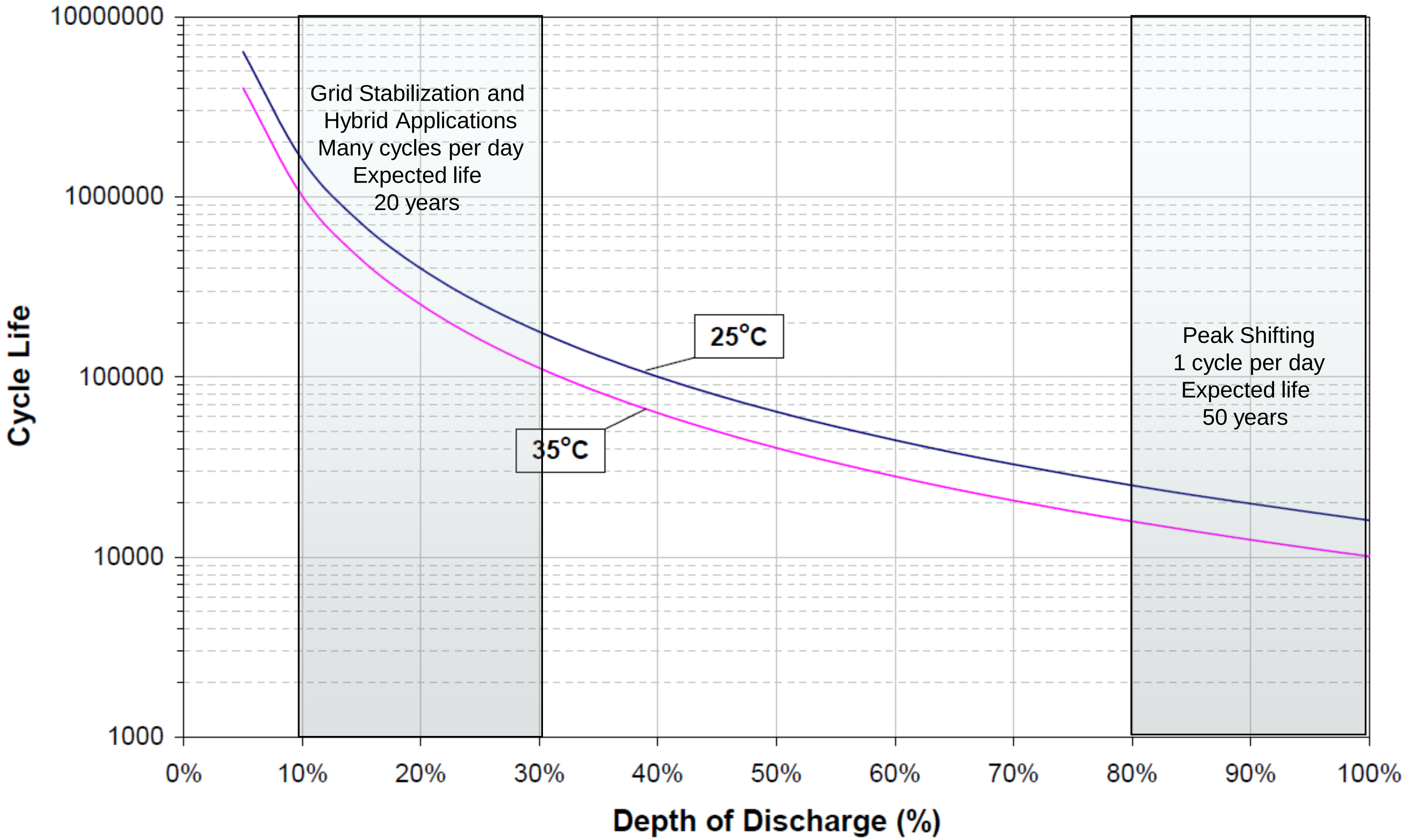


Battery Cycle Life to 80% Capacity



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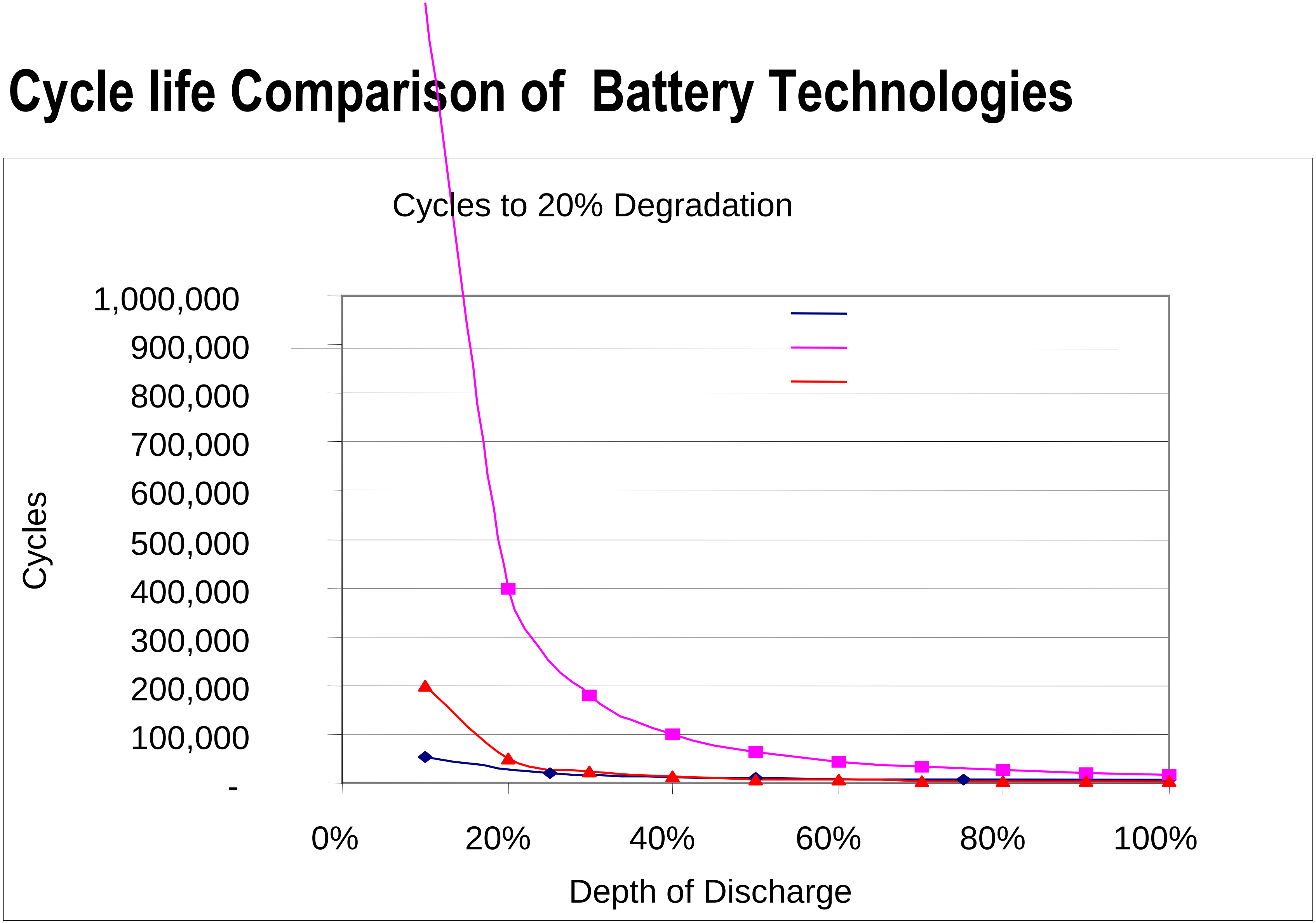

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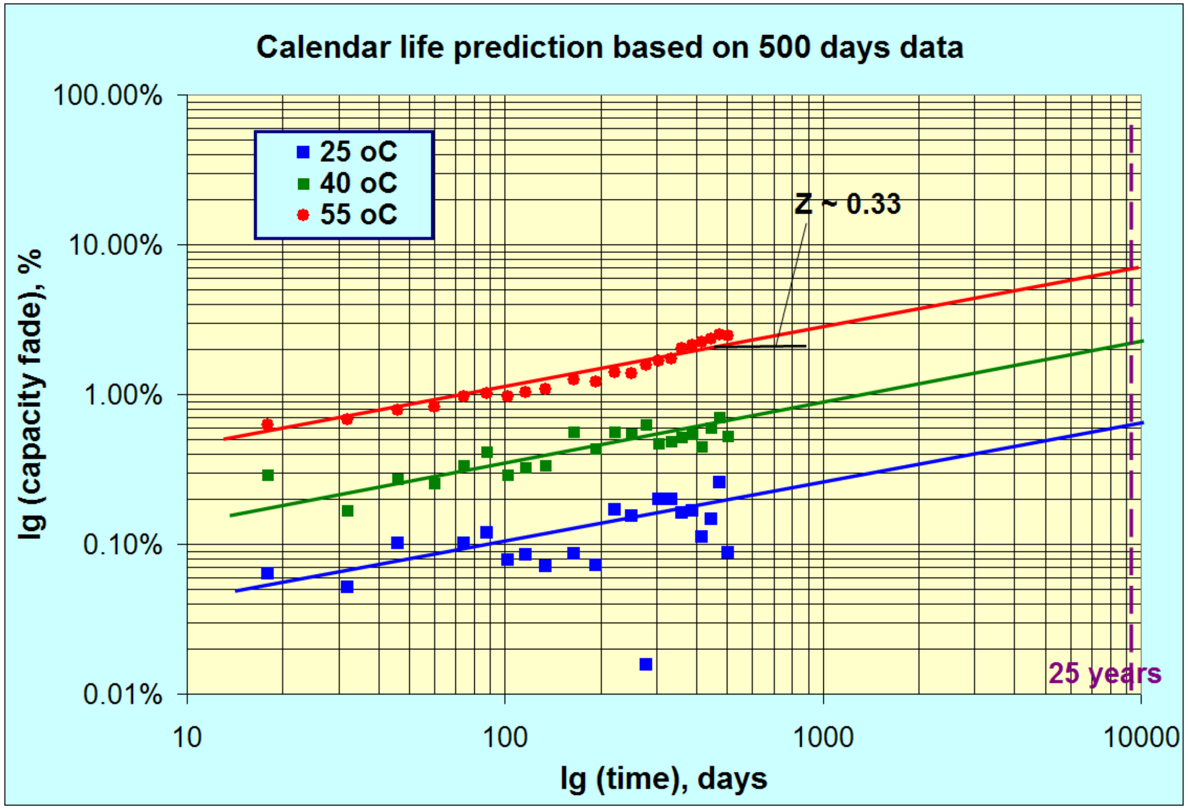

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  - Combine results for total capacity degradation vs. time

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Need Standardized Tests

- **Applications**
  - Vehicle Usage
  - Grid Energy
  - Grid Power
- **Assess**
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  - Energy
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10) Repeat steps 4 through 8 until battery is at 10% SOC.
11) Record open-circuit voltage after the 1 h rest before the discharge pulse, record voltage at 10 second point in charge and discharge pulse and record open-circuit voltage at end of 40 second rest for each SOC.

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15) Plot the discharge and charge power as a function of % SOC and discharged energy (Wh) at the 1 h rate.

PSOC - Partial State of Charge Test

from Sandia National Laboratory

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Impact of grid storage functions on battery degradation

NIST Workshop

PCS Architectures for PEV Fleets as Grid storage

06/13/2011

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Agenda

- Introduction
- Energy storage Grid applications
- Duty cycles
- Degradation modes
- Sample power applications
- closing

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Grid Storage Applications- Energy

- **Energy**
  - Hours
  - Peak shifting
  - Wind integration
  - PV integration

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Grid Storage Applications - high power applications

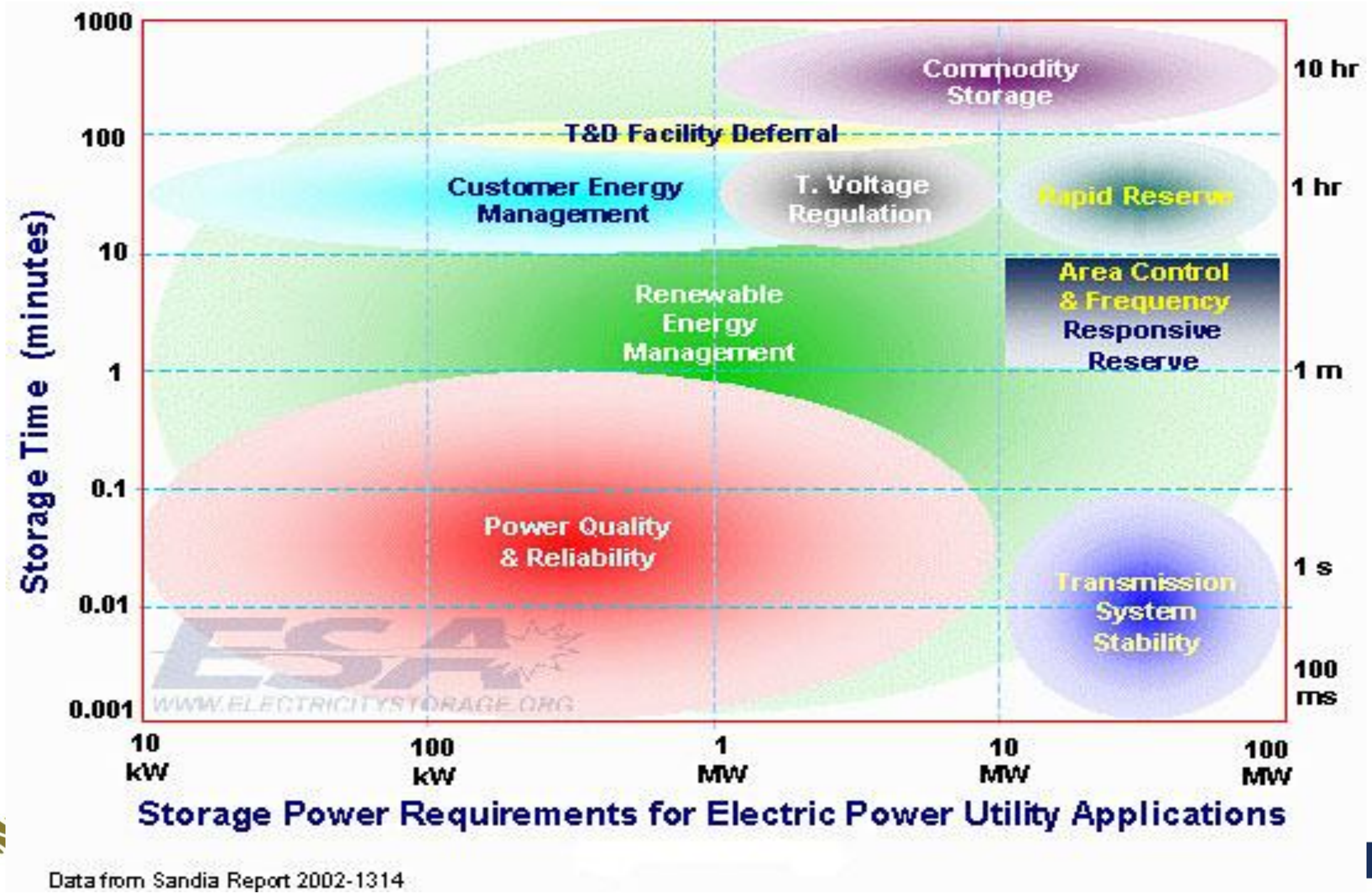
- Seconds to minutes
- Frequency Regulation
- Wind integration
- PV integration
- Microgrid integration
- Power quality solution
- Synthetic system inertia
- Synthetic System primary frequency control
- Black start

Energy Storage Attributes for These Applications

- **Energy rating**
- **Power rating**
  - charge
  - discharge
- **Cycling capability**
  - Useful depth of discharge
- **Energy efficiency**
- **Self-discharge characteristic**
- **Storage**
- **Calendar life**
- **Cycle life**

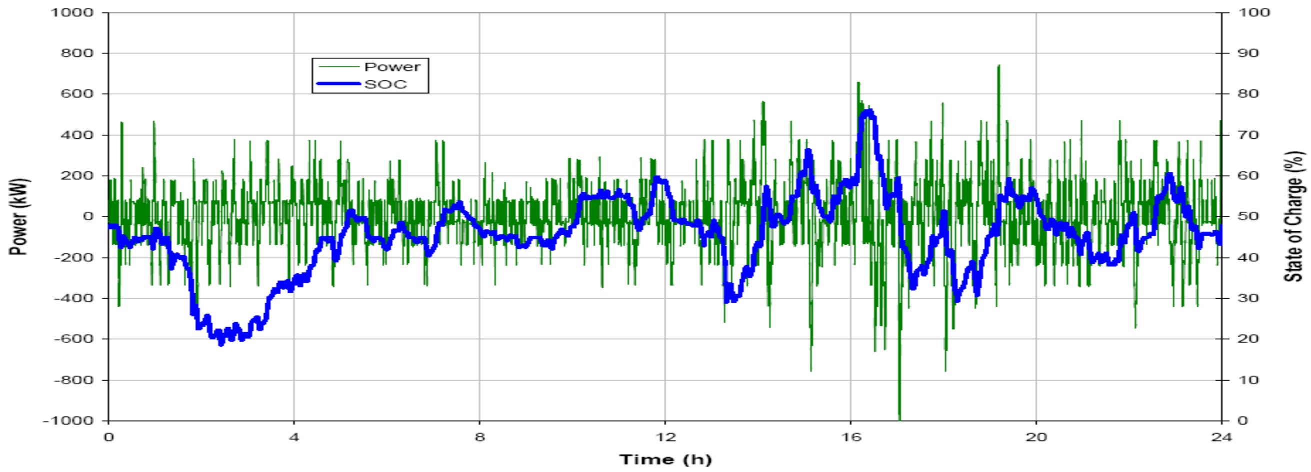
Energy Storage Applications-Time & Size Range

ESA (Electricity Storage Association), provides a map of applications



Example: Frequency Regulation

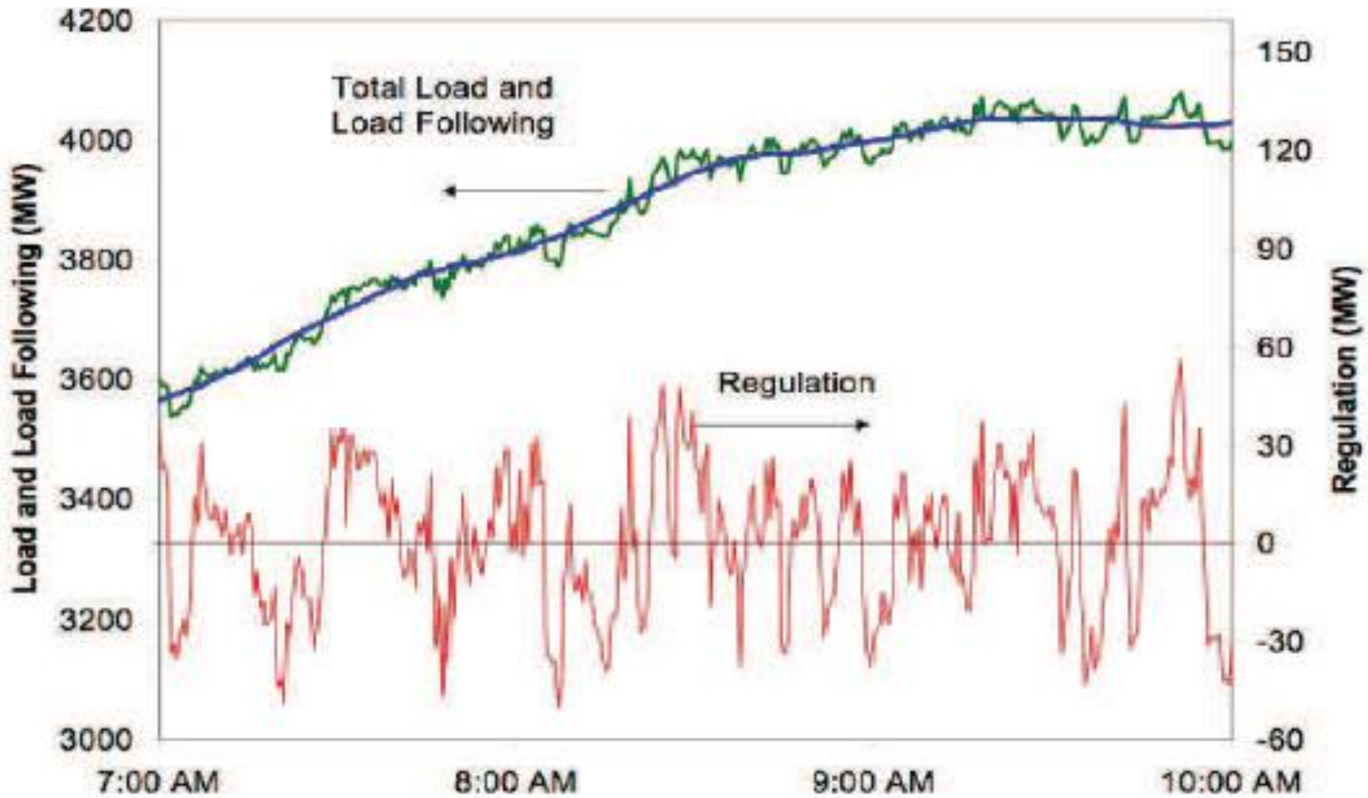
Typical 24 hour Profile



In two Years of Operation in PJM ISO

- **Performed over 250,000 small cycles and charged or discharged over 3,300 MWhr**
- **Less than two percent energy capacity degradation and no significant power capacity degradation**
- **Expected to maintain rated power and energy capacity for over twenty years without battery replacements or upgrades**

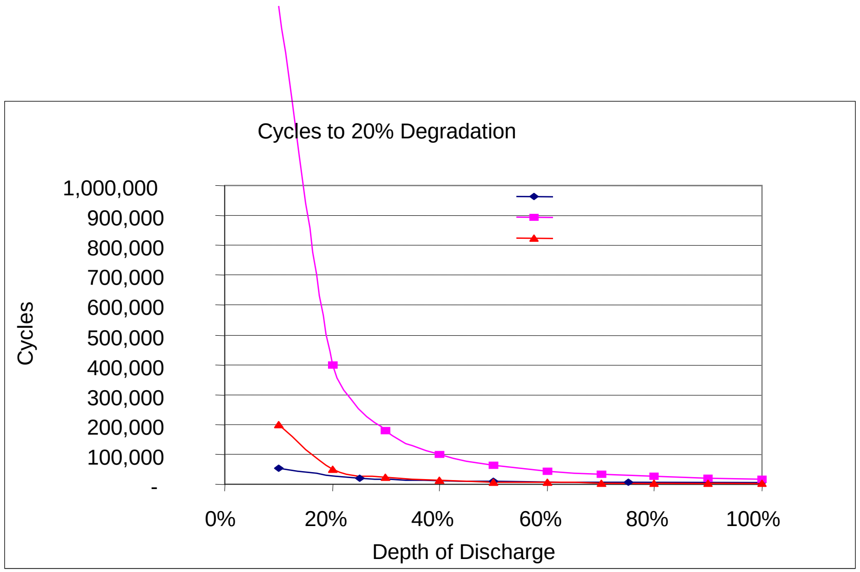
Grid Stability is maintained through the balancing of load and supply



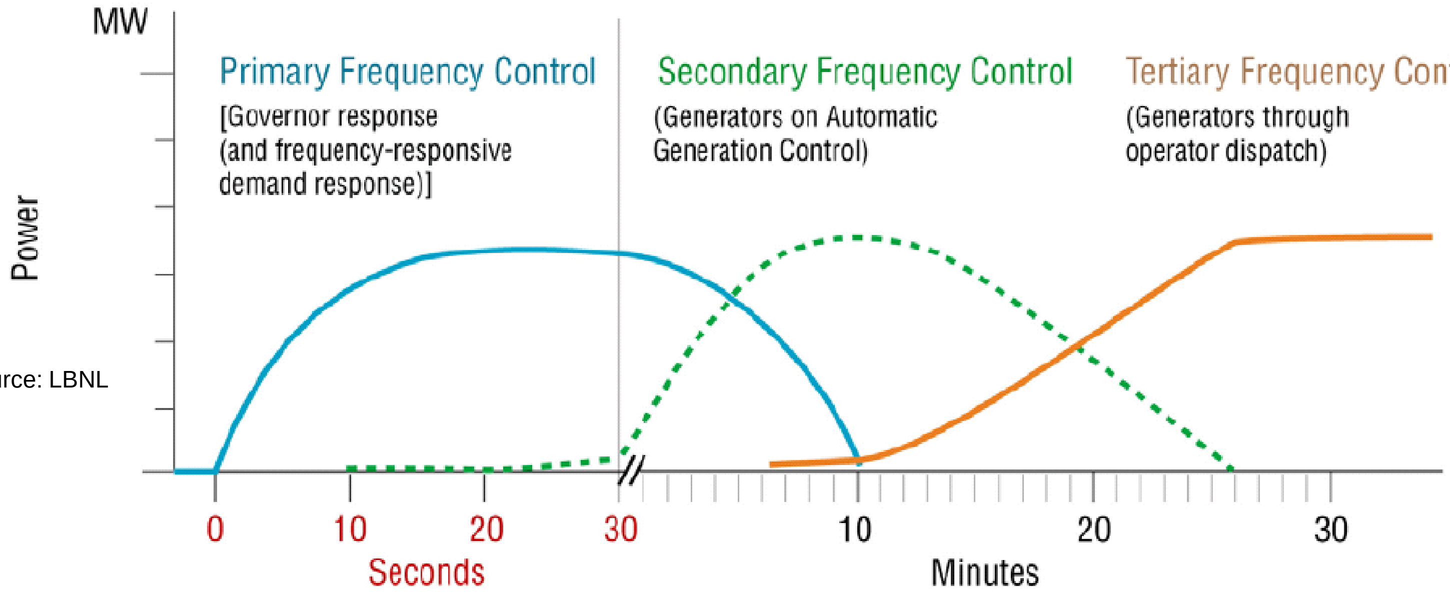
Regulation is near zero-energy service compensation for minute-to-minute fluctuations in total system load and uncontrolled generation

Battery technologies have different life characteristics dependent on DOD and number of cycles

- **At 100% depth-of-discharge, one technology provides 3-6 times more cycle life than others**
- **At low depth-of-discharge cycles, over 1 million cycles and up to 100X more life than others Li-Ion**

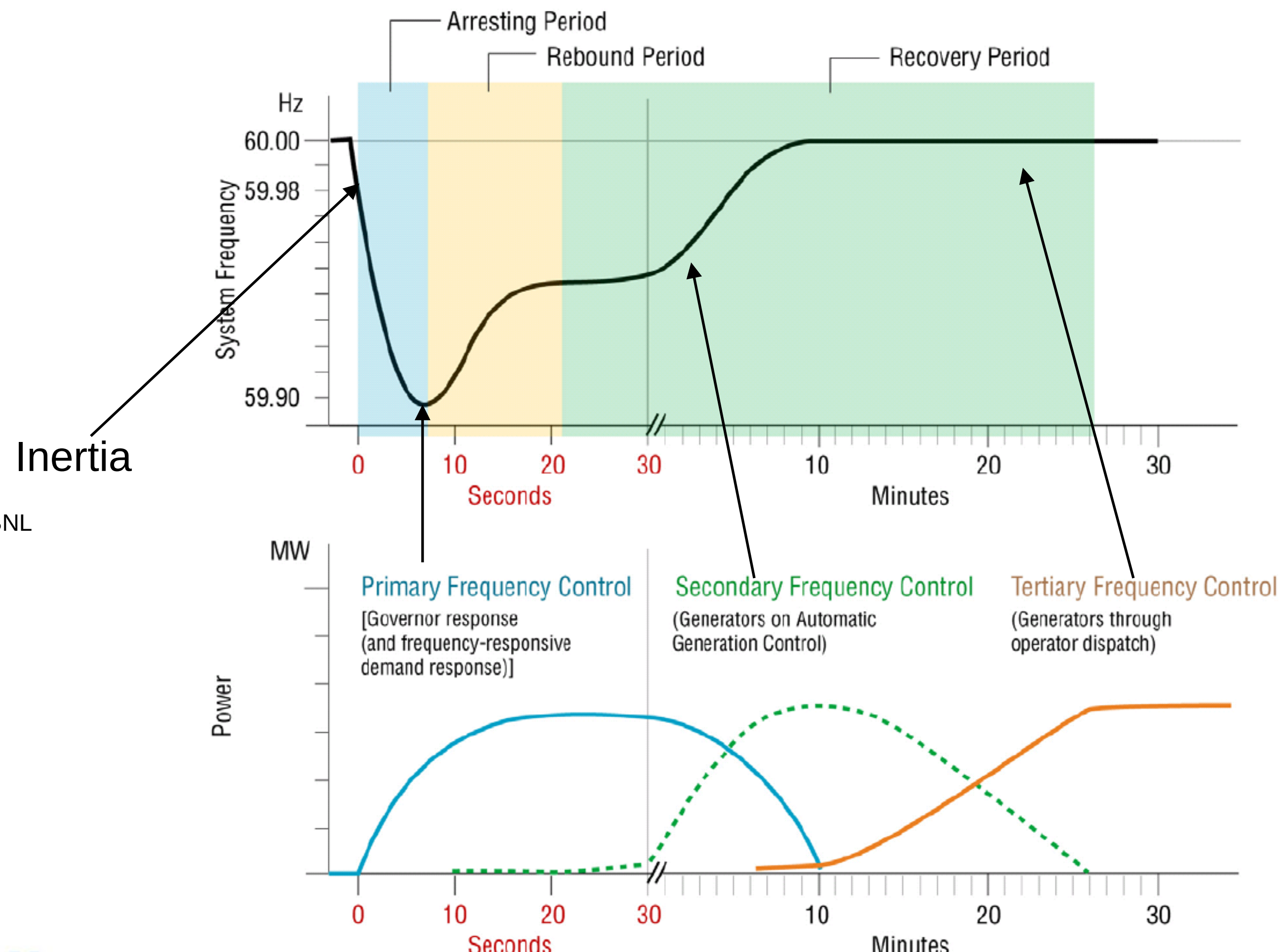


Types of Frequency Control by Timeframe



Source: LBNL

Actions of Frequency Control in a Loss of Generation Incident



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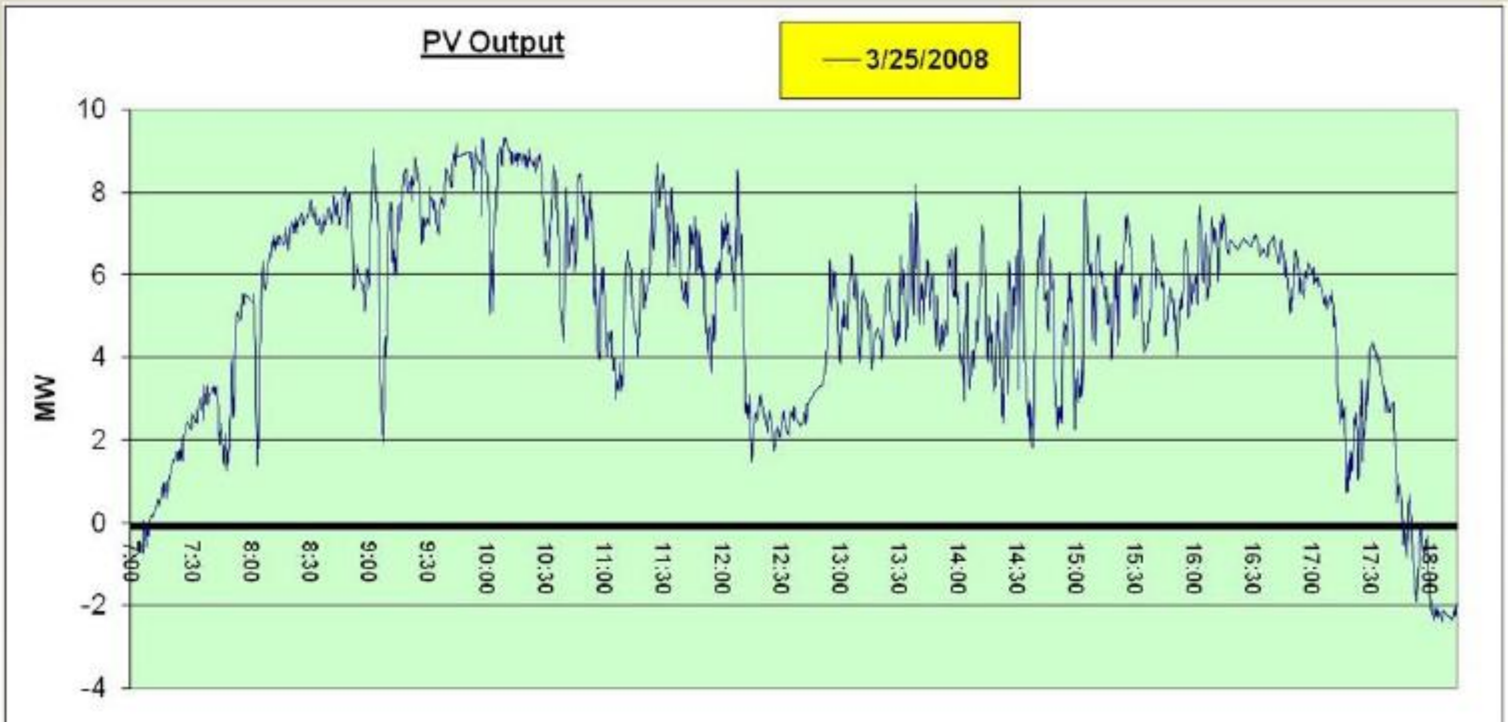

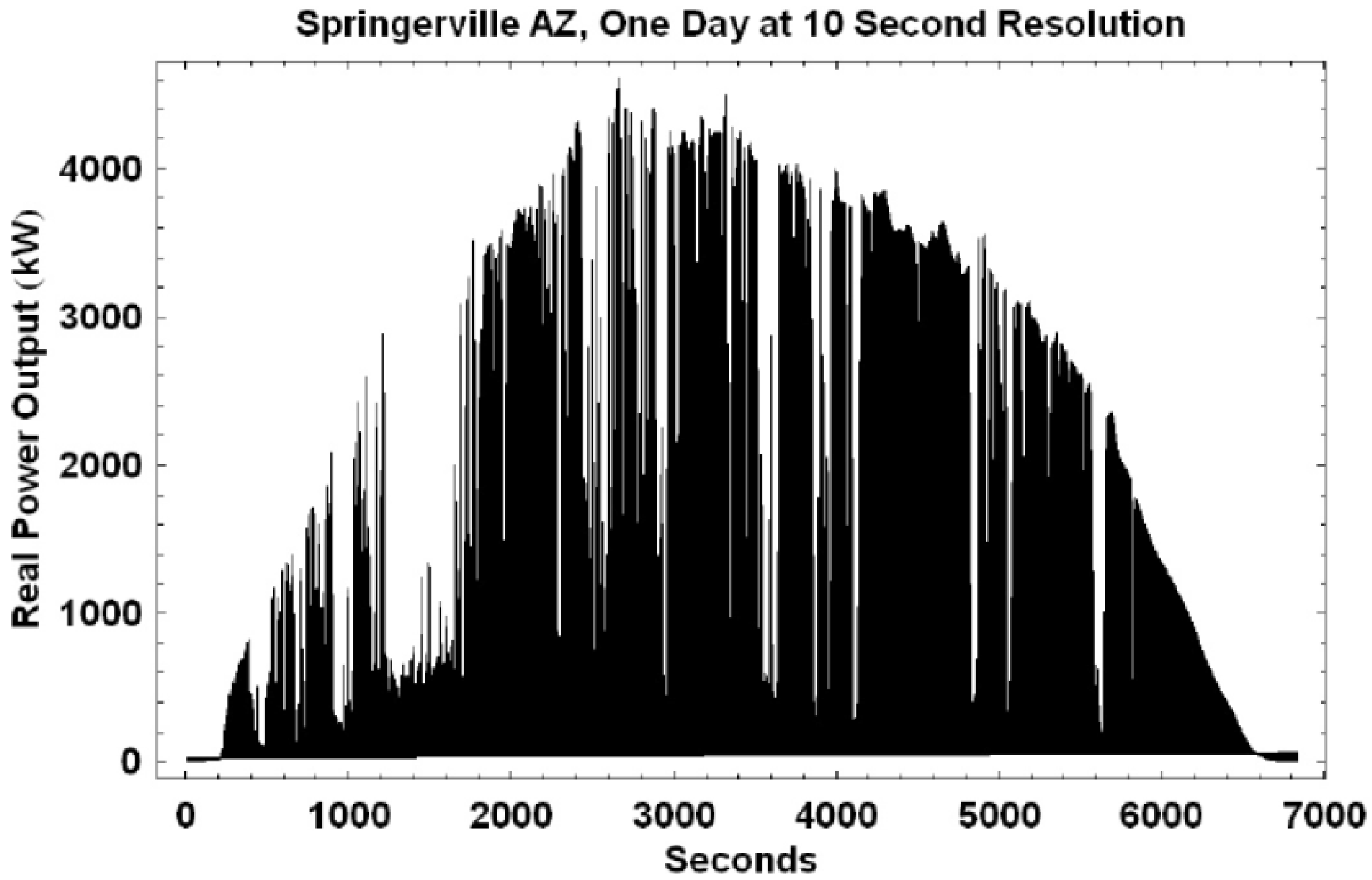

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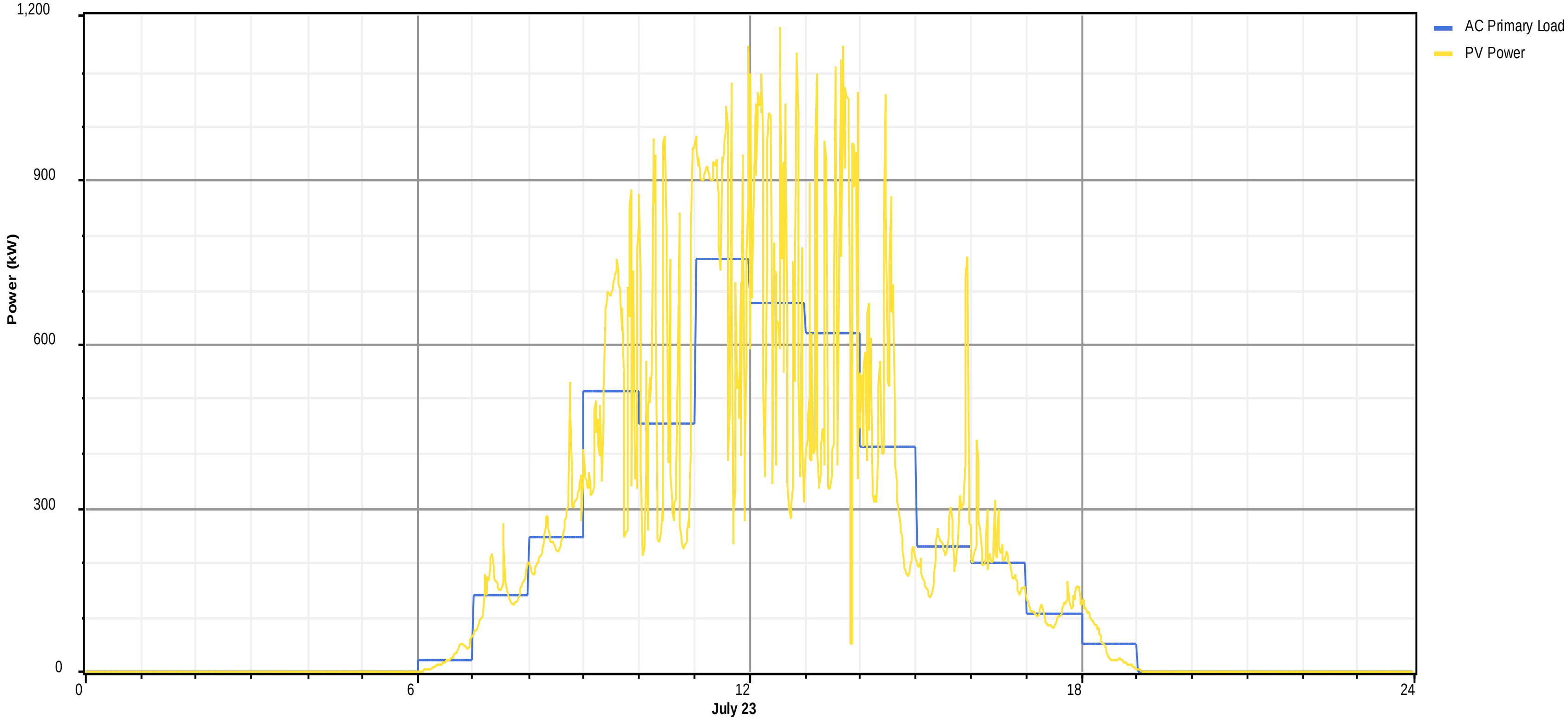

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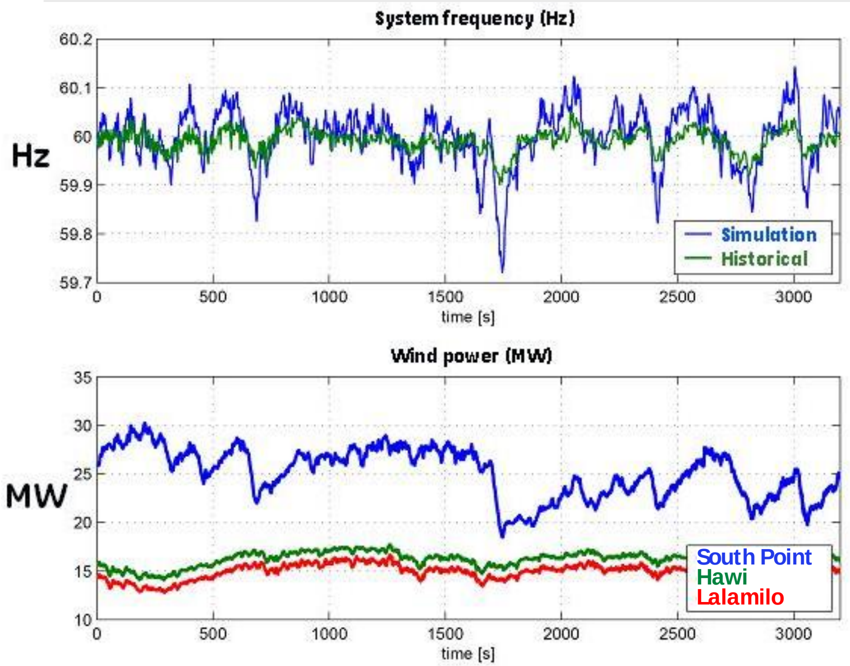

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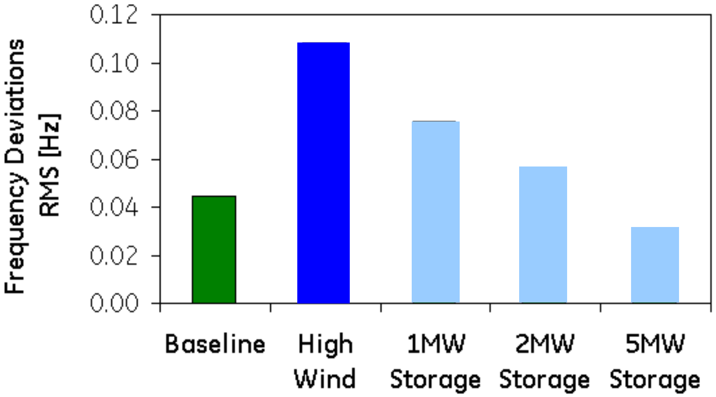

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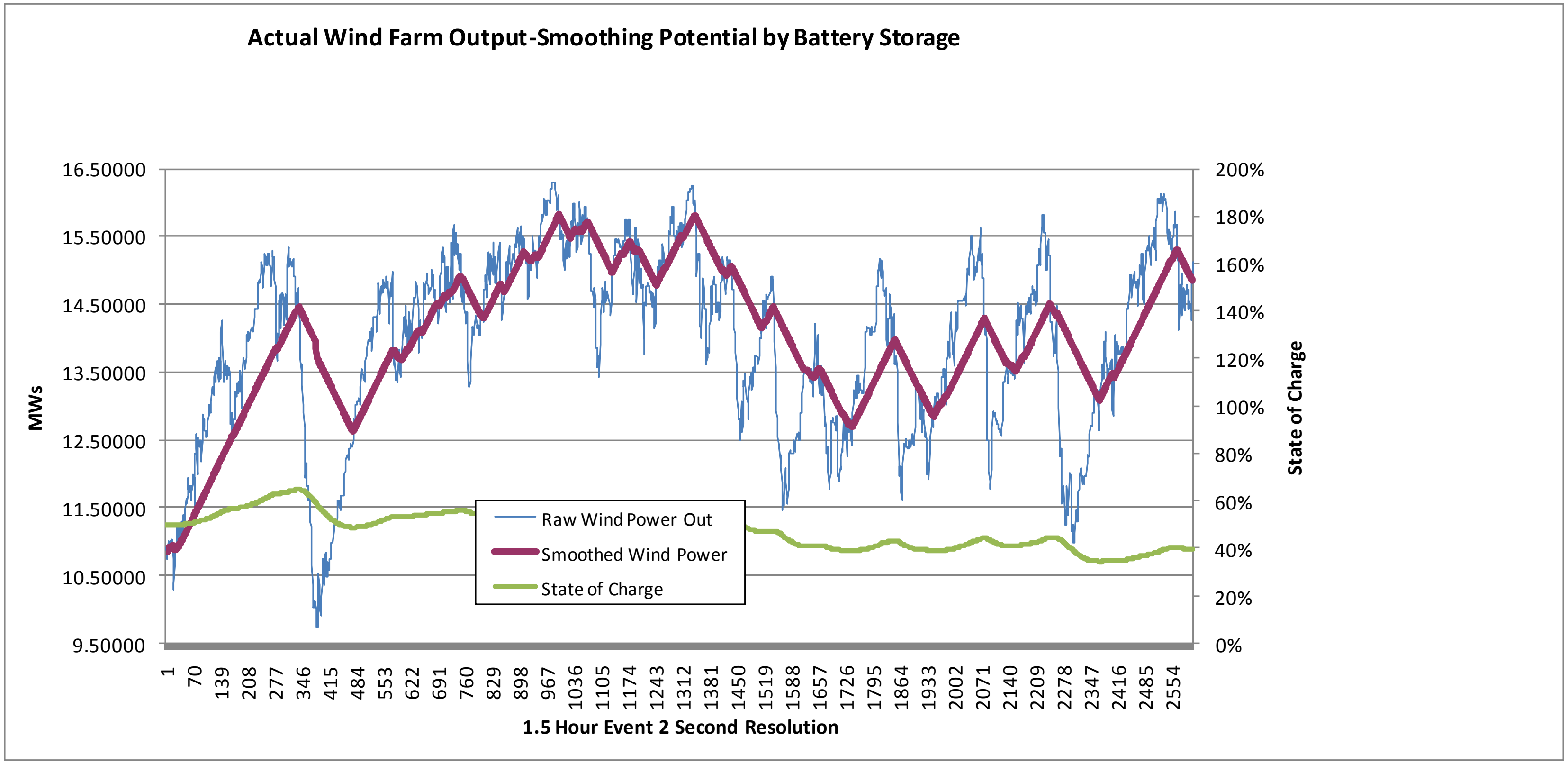

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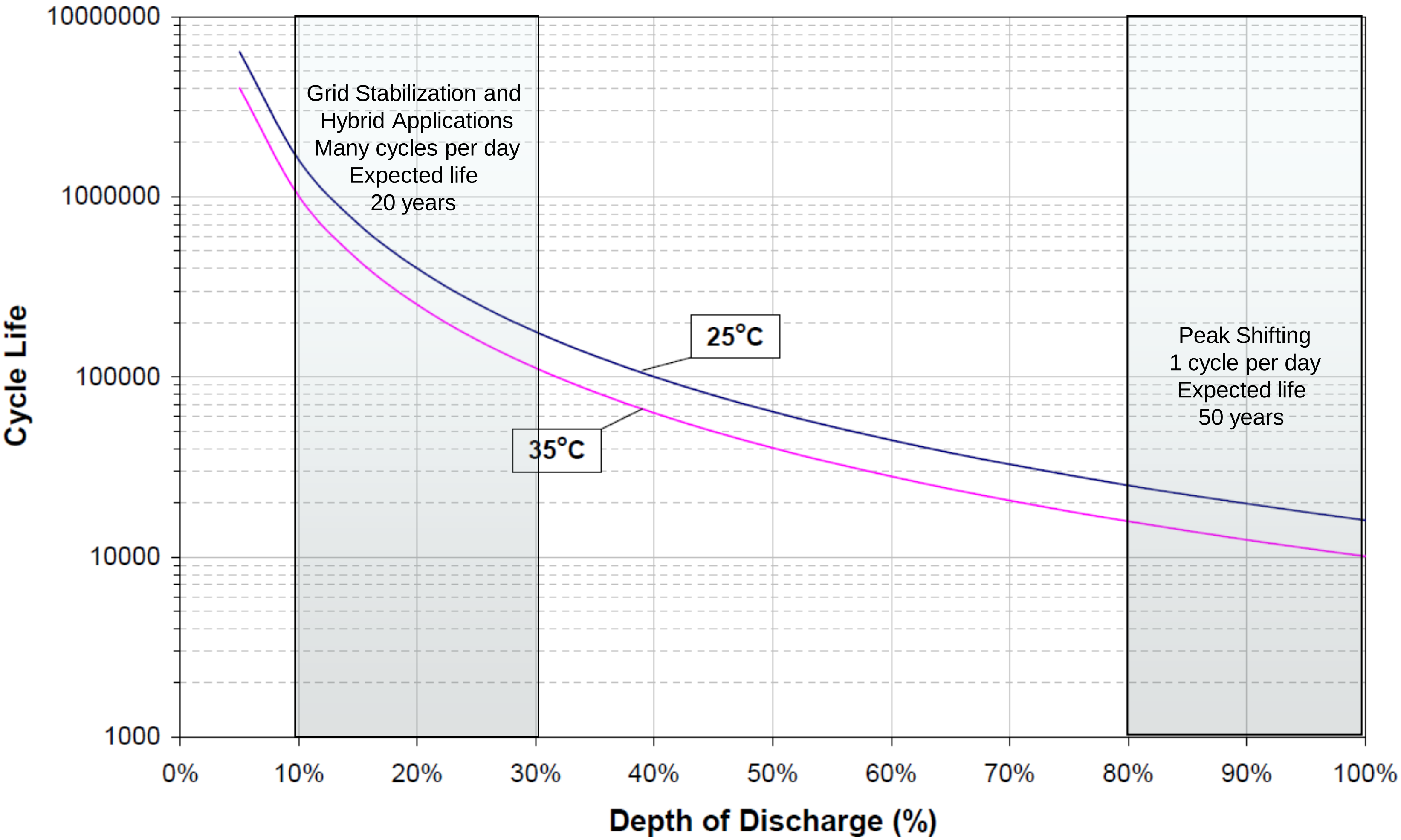

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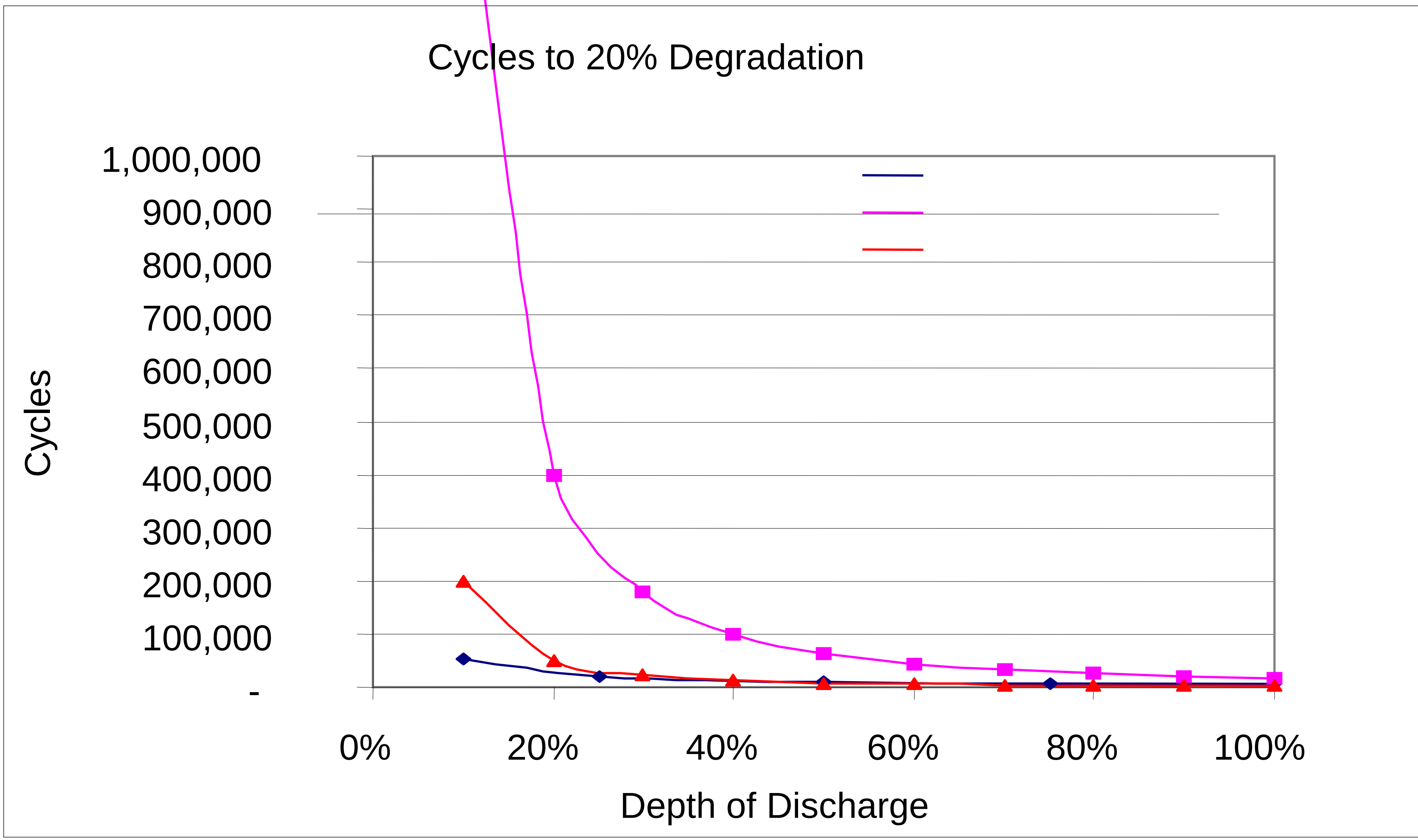

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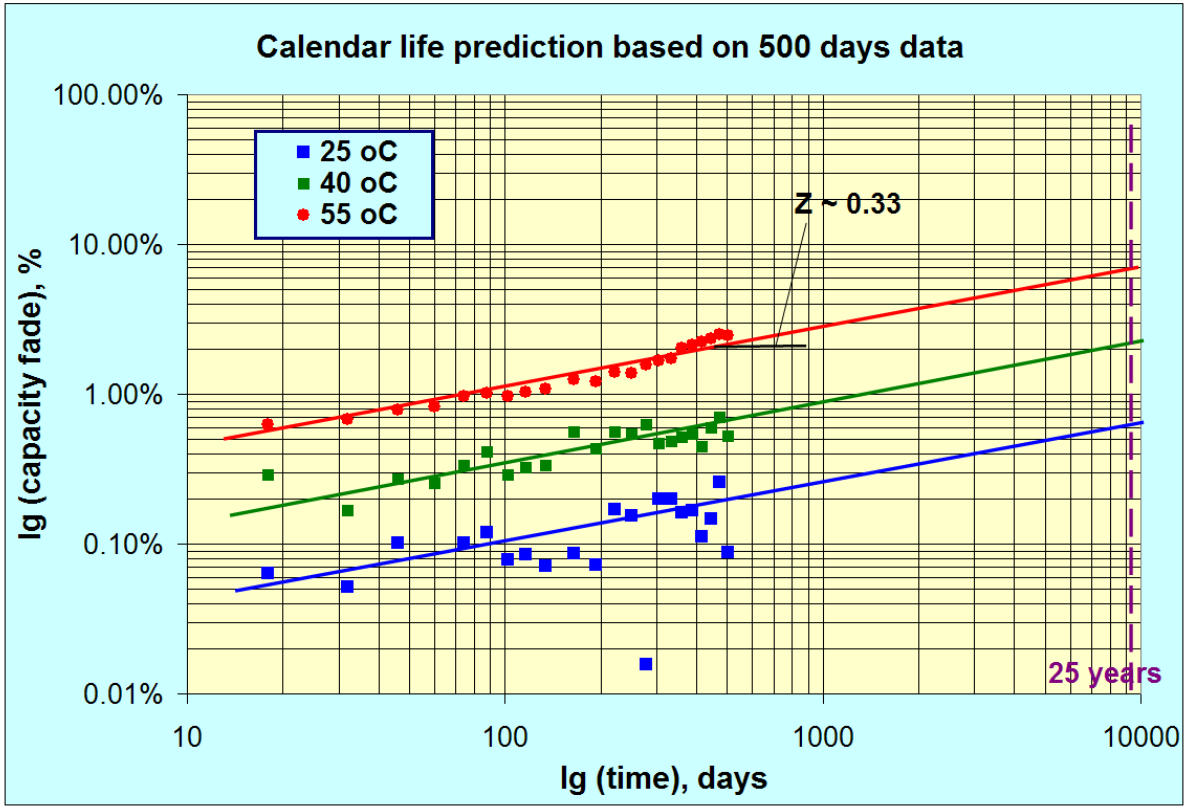

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Session 2.3

Skutt

Inverter/Storage functions to Support Renewable Integration

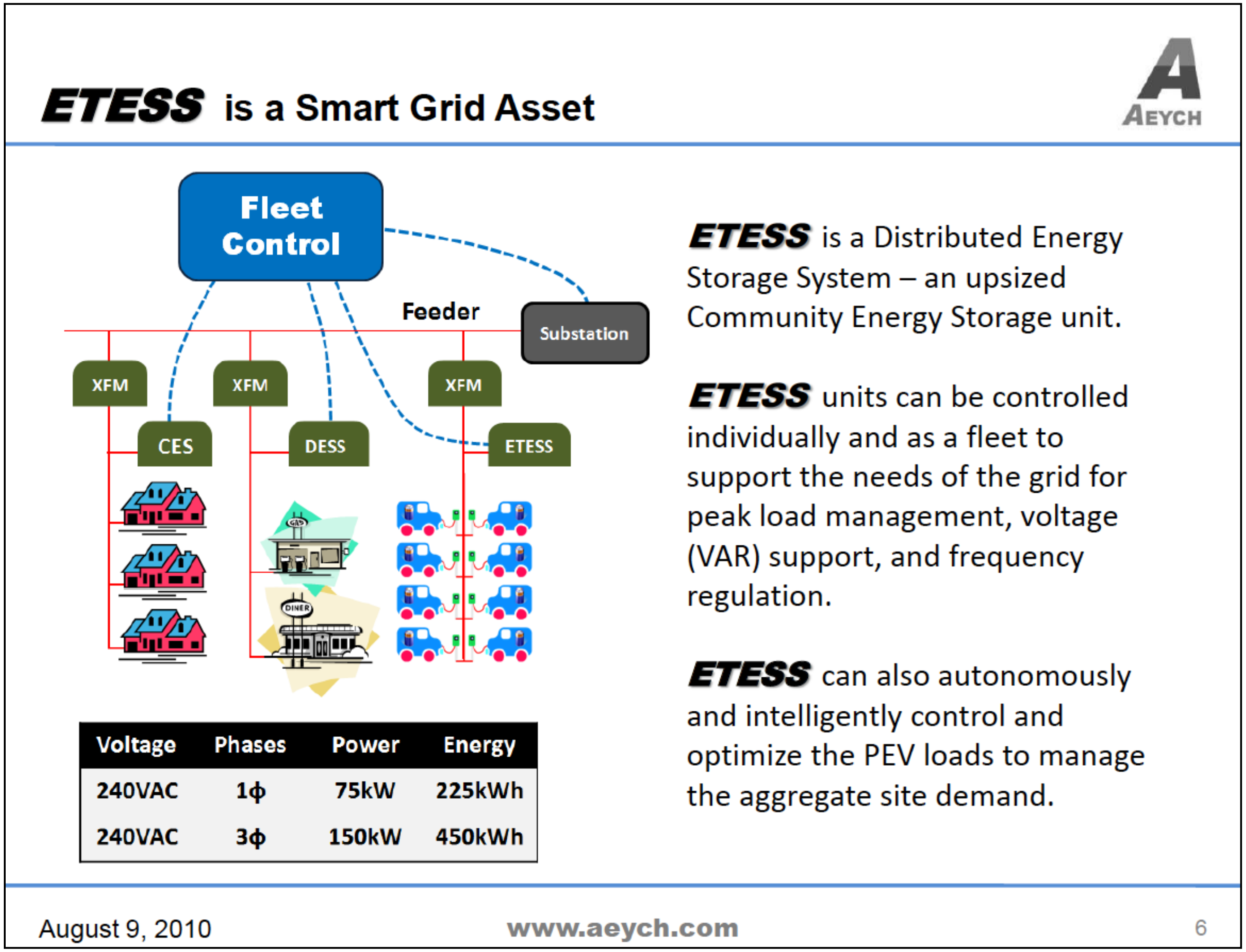
NIST Workshop on Power Conditioning System Architectures
for Plugin-Vehicle Fleets as Grid Storage

Session 2.3: How might a PEV Fleet aid in integration of distributed variable renewable generators?

Glenn Skutt

powerhub SYSTEMS

PEV Integration with Storage

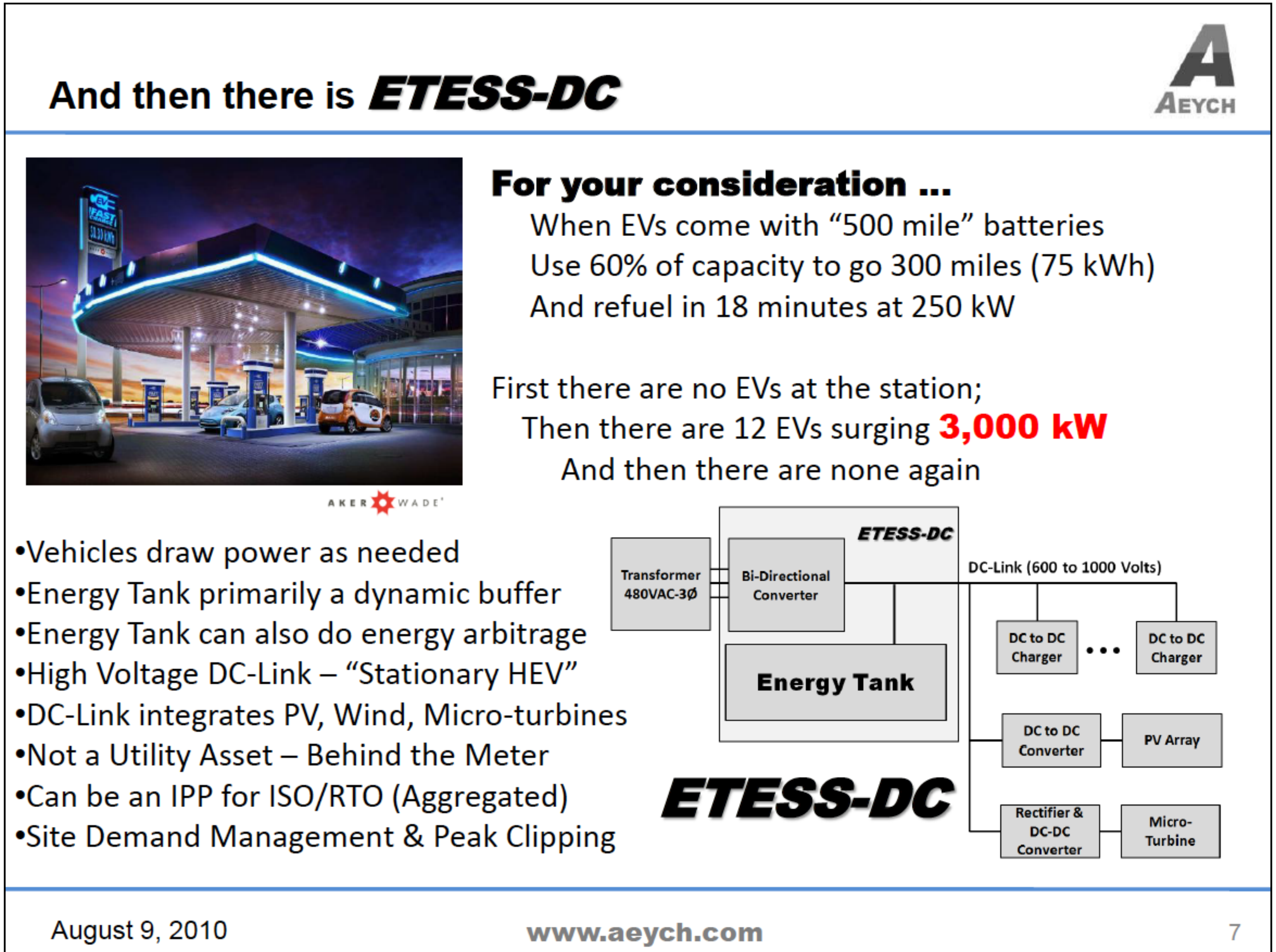


One vision: Distributed energy storage units controlled as a part of PEV fleet management

Requires storage system inverter control and integration with PEV activities

http://www.neny.org/download.cfm/McGlynn.pdf?AssetID=1492

PEV Rapid Charge Stations



Integration of stationary storage with the intermittent load of rapid charging PEVs.

Stationary storage managed for PEV charging AND for grid integration

http://www.neny.org/download.cfm/McGlynn.pdf?AssetID=1492

Inverter Control/Communications Development Efforts

- Standards Development:

EPRI: “PV & Storage Inverter Interactions using IEC 61850 Object Models and Capabilities”

NIST Priority Action Plan 7: “Electric Storage Interconnection Guidelines”

IEC 61850-4-720 and others

IEEE 1547.8: Draft Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies For Expanded Use of IEEE Standard 1547

- Various Demonstration Programs

Standards: Communications Functions

- The DER/ES control standardization efforts share some basic functions
- Use Case driven design
- Example: (from NIST PAP07 Use Case Document)

BROADCAST/MULTICAST REQUEST FUNCTIONS

4.1 Energy Use Cases

4.1.1 Use Case: Electric Vehicle Load Management

4.1.2 Use Case: PEV Participates in Utility Events

4.2 Utility Distribution Modeling and Analysis of ES-DER

4.2.1 Use Case: Distributed Energy Resource (DER) Management

4.2.2 Use Case: Management of DER Systems

4.2.3 Use Case: Secondary DA Functions – Automated Distribution Systems with Significant DER

4.2.4 Use Case: Short-Term DER Generation and Storage Impact Studies

4.2.5 Use Case: Optimal Placements of Switches, Capacitors, Regulators, and DER

4.3 Ancillary Services Functions

4.3.1 Use Case: Volt/Var Optimization: Energy Conservation Mode

4.3.2 Use Case: Emergency Override: Maximum Var Support Mode

4.3.3 Use Case: Static Var Mode

4.3.4 VAR Mode PV4: Passive Mode

NIST Smart Grid PAP07

- Examples of direct commands to an ES-DER system include:
  - Connect/disconnect from grid
  - Charge to % of capacity at specified ramp rate or for specified length of time
  - Discharge to % of capacity at specified ramp rate or for specified length of time
  - Pricing signal to provide information to an autonomous ES-DER system on which to make charging/discharging decisions.

Example: EPRI Inverter Volt-VAR Control for Energy Conservation Mode

- One example of a function being defined for Inverter functionality in a DER/ES environment
- Normal Energy Conservation Mode –utility’s calculation of the most efficient and reliable VAR levels for PV inverters at specific distribution points of common coupling (PCC). Can also help compensate for local low voltage due to PEV kW loads on the circuit.
- Uses an array voltage levels and their corresponding VAR levels.
- Voltage levels range between V1 and V2 in increasing voltage values.
- Values between setpoints are interpolated to create at a piecewise linear volt/var function.
- The corresponding VAR levels define the percent of Qmax (ranging between -100% and +100%) being requested for the voltage level.

Volt/Var Function (cont.)

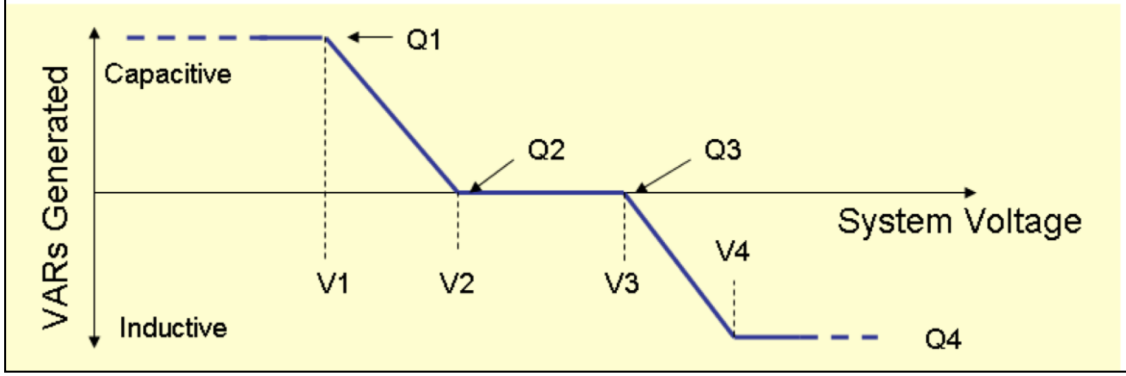
- An example of volt/var settings for this mode.
- VAR value between V_{min} and V1 is assumed the same as for V1 (Q_{max} in this example).
- Same is true for the VAR value between V4 and V_{max} ($-Q_{max}$ in this example).

Mode PV1 – Normal Energy Conservation Mode

Example Settings

Voltage Array		VAR Array (%)	
V1	115	Q1	100
V2	118	Q2	0
V3	122	Q3	0
V4	126	Q4	-100

VAR Ramp Rate Limit – fastest allowed change in VAR output in response to either power or voltage changes	50 [%/second]
Randomization Interval – time window over which mode or setting changes are to be made effective	60 seconds



Example: Request Real Power (Charge or Discharge Storage)

The utility/ESP or the Customer EMS takes the following actions:

1. (Optional) Request status of PV/Storage system: Request a pre-defined set of the status information, including the status values, the quality flag, and the timestamp of the status (see Function PC6 for details of status points).
2. Issue command to request real power (charge/discharge) setpoint for the storage system:
   a. Command **to adjust the real power charge/discharge setpoint for the storage system**
   b. Requested **ramp time for the PV/storage system** to move from the current setpoint to the new setpoint (optional – if not included, then use previously established default ramp rate)
   c. Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately, (optional – if not included, then default time window for this function will be used)
   d. Timeout period, after which the PV/Storage system will revert to its default status (optional – if not included, then default timeout period for this function will be used)
   e. Storage charge from grid setting (yes/no)
3. Receive response to the command:
   a. Successful (plus actual real power setpoint)
   b. Rejected (plus reason)

General List of Inverter/Storage Functions for PEV/DER Integration

Top Level Functions:

- Scheduled charge/discharge and advanced scheduling
- Volt VAR Control
- Watt/Frequency control
- Energy Arbitrage
- Renewables integration
- Harmonic Cancellation
- Voltage Sag Ride-Through

Implementation level:

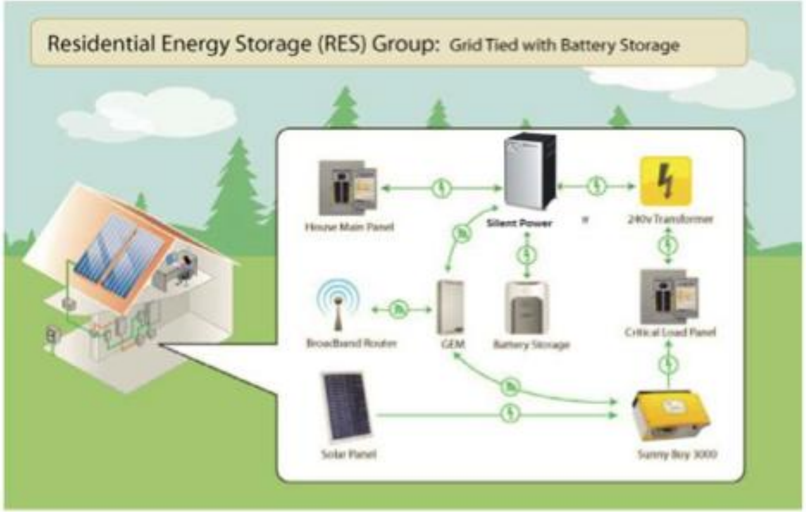
- Sense Voltage and Frequency
- Sense time rate of change of voltage and frequency
- Determine actual +/- real/reactive power output
- Determine maximum available +/- real/reactive power available
- Change to any given combination of available +/- real/reactive power
- Report nameplate information
- Report current state of V, f, P, Q, P/Q available

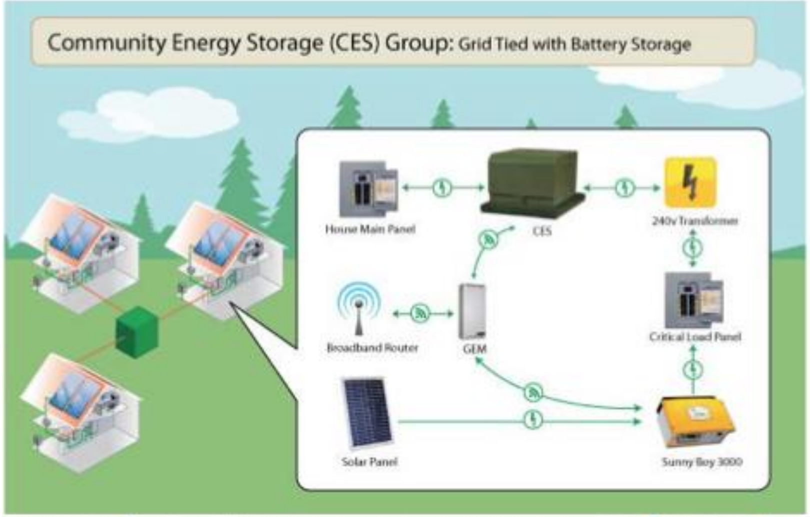
High level functions of converters or systems that control converters :

- Implement P/f schedule, i.e. P(f)
- Implement Q/V schedule i.e. Q(V)
- Implement +/- P activity as function of price information
- Provide maximum available +/- P/Q on demand subject to limits (available P/Q, V/f limits, machine limits)

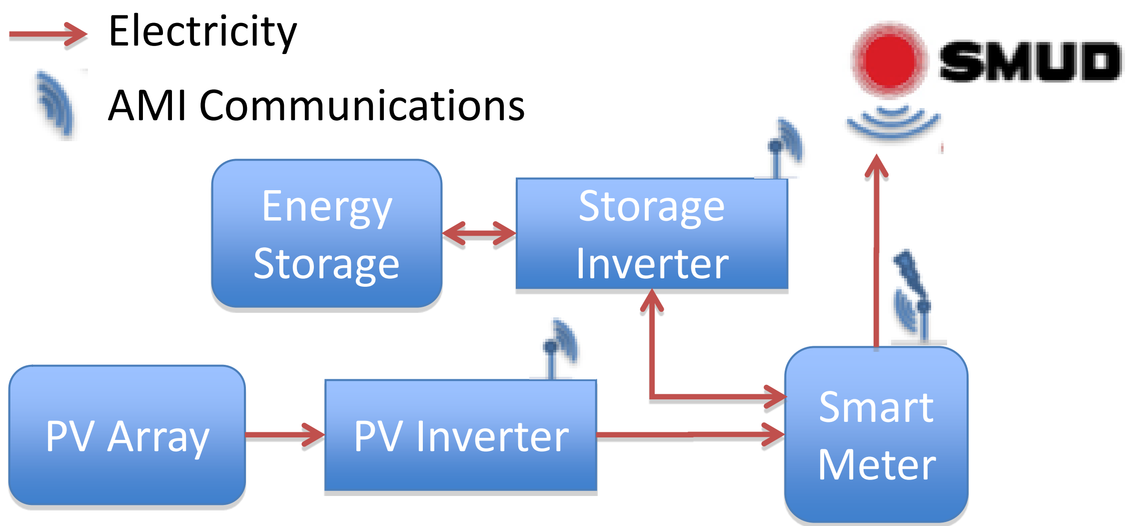
Demonstration Example: Sacramento High Penetration Solar Demonstration Project

- Control group of 25 homes with PV
  - RES Group – 15 units
    - UL listed units
    - 10kWpeak/8.8 kWh Li-ion batteries
  - CES Group – 3 units
    - Connected to secondary of 50 kVA pad mounted transformers serving 9-12 homes
    - 30 kW/30 kWh Li-ion batteries
- Utility/Customer portals monitor PV, storage, customer load
- Sending price signals to affect changes in customer usage
- Quantifying costs and benefits of this storage deployment to gain insights to broader application for SMUD





SMUD Demo Inverter Functionality



- Inverter Communications
  - Demonstrate Inverter Monitoring via AMI communication from smart meter to inverter
  - Demonstrate receiving data, querying for faults, sending control signals
  - Utilized as actively controlled contributors versus passive devices on the grid
- Functions include
  - firming of PV output through active regulation of energy storage inverter to compensate for fluctuations in PV output
  - scheduled charge and recharge for load shifting

Summary

- Plenty of opportunity for inverters to interact with PEV and other DER deployments
- Emerging standards for inverter control
- Inverters are generally underutilized relative to the functionality they can provide
- Combination of storage with PEV charging will be important for high PEV use levels

2) Use of EV as Grid Storage

Session 2.5
Ashtiani

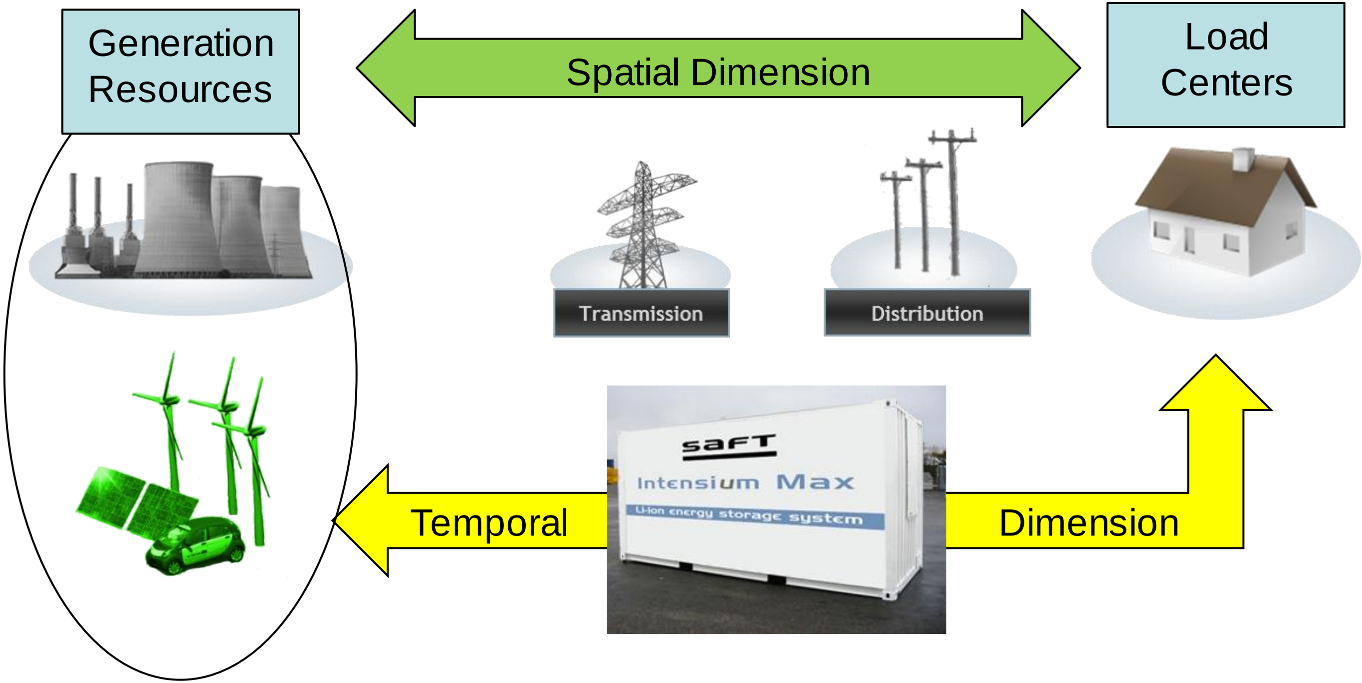
Dual Use of PEV Batteries: V2G Storage and Propulsion

Cyrus Ashtiani

- At projected 1,000,000 plug-in vehicles (<1% of registered passenger vehicles on the US roads), each carrying a ~15kWh store of energy, a sizable 15GWh distributed storage system will become available
- While plugged into the grid, this distributed storage resource can serve grid's diverse storage needs
- Most common grid storage applications
  - > Frequency Regulation
  - > Ramping for renewable resources
  - > µgrids, islanding
  - > Backup power
  - > Network decongestion by time-shifting load or generation, ..
  - > …

Role of Storage in The Grid: Time & Space Divides

- Two dimensions of separation between generation & load centers



The Challenge

- Batteries are optimally designed to meet specific application needs & requirement (no universal all-purpose battery)
  - > A PEV battery is specifically designed to serve PEV loads
- Attempts to serve multiple duties tend to make larger, more expensive systems. Cost & size are major barriers
- Additional duties imposed on the battery by the grid, while plugged-in, will have significant wear & tear on the battery
  - > Who pays the initial capital or ownership costs?
  - > Who benefits from the grid usage?
  - > How stakeholders get compensated for use of battery?
  - > How these transactions impact the battery warranty?

Grid Applications

- Grid applications are diverse with very different duty cycles:
  - > The backup power (UPS), e.g., keeps the storage at high SOC and only occasionally taps into the battery with deep DOD at near constant rate
  - > The frequency regulation (FREG), keeps the battery engaged fully when dispatched with random sharp pulses of a few seconds bi-directionally (charge & discharge). Many shallow cycles superimposed on a usually deep daily DOD cycle
  - > Time shifting involves charging and discharging the battery at constant rates intercepted by periods of alternately staying at high & low SOCs
- Different duty cycles & loads, call for very different system engineering especially from thermal management perspective

Regulatory Barriers, Mission Conflicts

- Many ancillary services are purchased as “options to access a resource at call” and require a guaranteed “set-aside capacity”, not a randomly available resource
- As a utility customer, PEV, is interfaced with an LSE (Load Serving Entity) which is within state jurisdiction and regulated by Public Utility Commissions (PUCs)
- The bulk of frequency regulation is in “organized markets” and implemented at the HV transmission at 34kV and 69kV lines. It’s an intrastate transaction under Federal Gov. Jurisdiction typically operated by ISO/RTO’s regulated by FERC
- NERC sets the standards for system reliability for the north American grid (US & Canada)

The Opportunity

- Continental U.S. military bases are ideally suited as a prototype for green community µgrids
- Such µgrids communities can embody multiple synergistic concepts: distributed renewable generation (DRG), stationary distributed storage resources (community type ES, as well as larger scale for backup power & regulation), EV & PEV, and charging stations within the µgrid
- EV & PEV's within that green community prototype can then become an integral part of the grid, and serve as a last resort rather than day to day functions of the grid
- Opportunity for DOD to take a leadership role in addressing nation's looming energy security & dependence on foreign oil

Backup Slides

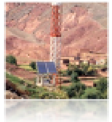
Saft Group in 2010

*1.40 $/€ conversion rate

Space

Defence

Industrial standby



Telecommunication

Specialty Battery Group

$364MM

44 %

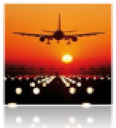
High performance primary and rechargeable lithium and silver batteries for the electronics, defence and space industries.

Industrial Battery Group

$464MM

56 %

Rechargeable nickel and lithium-based batteries for demanding industrial applications.



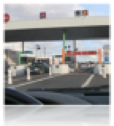
Aviation

Clean Energy Storage

Joint-Ventures:

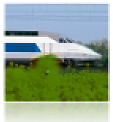
- Johnson Controls-Saft
  HEV and EV batteries
- ASB Group
  Thermal batteries

Equity accounted



Metering and Professional Electronics

Emergency Lighting



Rail and Mass Transit

SAFT

International Presence & Character

- ❑ Presence in 19 countries
- ❑ Saft Jacksonville is its 16th wholly owned mfg. site and the 6th in the U.S.
- ❑ 4,000+ employees worldwide
- ❑ Saft leads the Li-ion battery market for worldwide observation, scientific and telecom satellites
- ❑ 2/3 of the world's civil & military aircraft rely on Saft batteries for starting & backup power
- ❑ World leading supplier of advanced battery systems for defense on land, at sea, and in the air

2) Use of EV as Grid Storage

Session 2.5
Hsieh

Business and Policy for Plug-In Vehicle Grid Uses

NIST/DOD PCS Workshop

June 13, 2011

Outline

- Frequency regulation and spinning reserves provides significant revenues for existing storage projects
- Current rules allow non-generating resources (even loads and charge-only EVs) to provide frequency regulation
- Bidirectional applications face technical constraints
- Variable charging may provide a sufficient business case

Frequency Regulation Revenues from Storage

Existing commercial deployments show promising performance

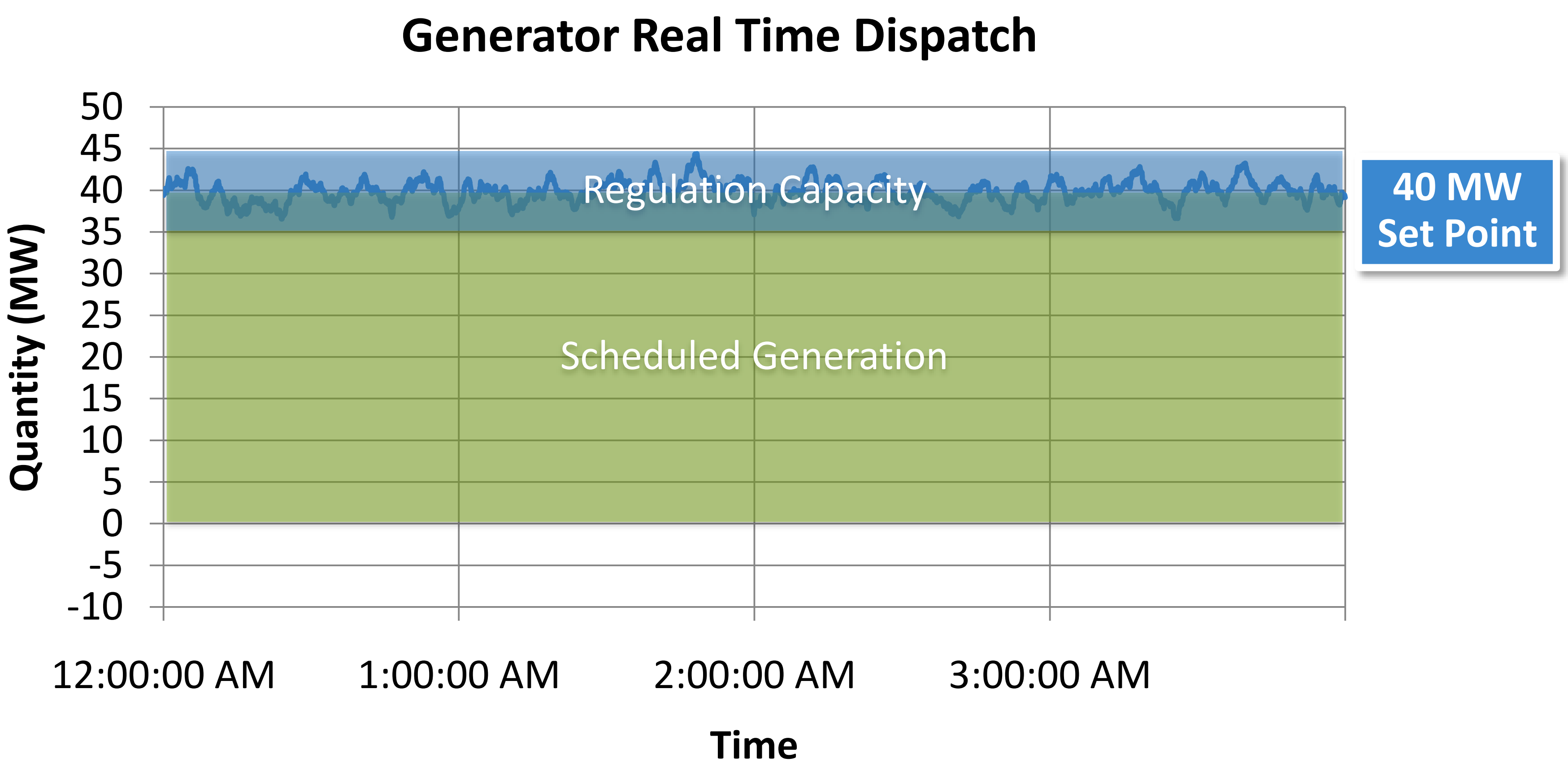
Ancillary Services from Non-Generators

Most markets exhibit few policy barriers

- FERC Order 890 (2007):
  - *"Ancillary services by load resources should be permitted where appropriate on a comparable basis to services provided by generation resources."*
- PJM Demand Response Programs
  - Curtailment Service Providers can aggregate loads
  - Eligible to bid into Energy, Capacity, Day-Ahead Scheduling Reserves, Synchronized Reserve and Regulation
- CAISO Regulation Energy Management (2/2011)
  - Specific implementation allowing storage to sell frequency regulation
  - Provides an energy set point to manage state of charge
  - Could be used to charge an EV battery while providing regulation

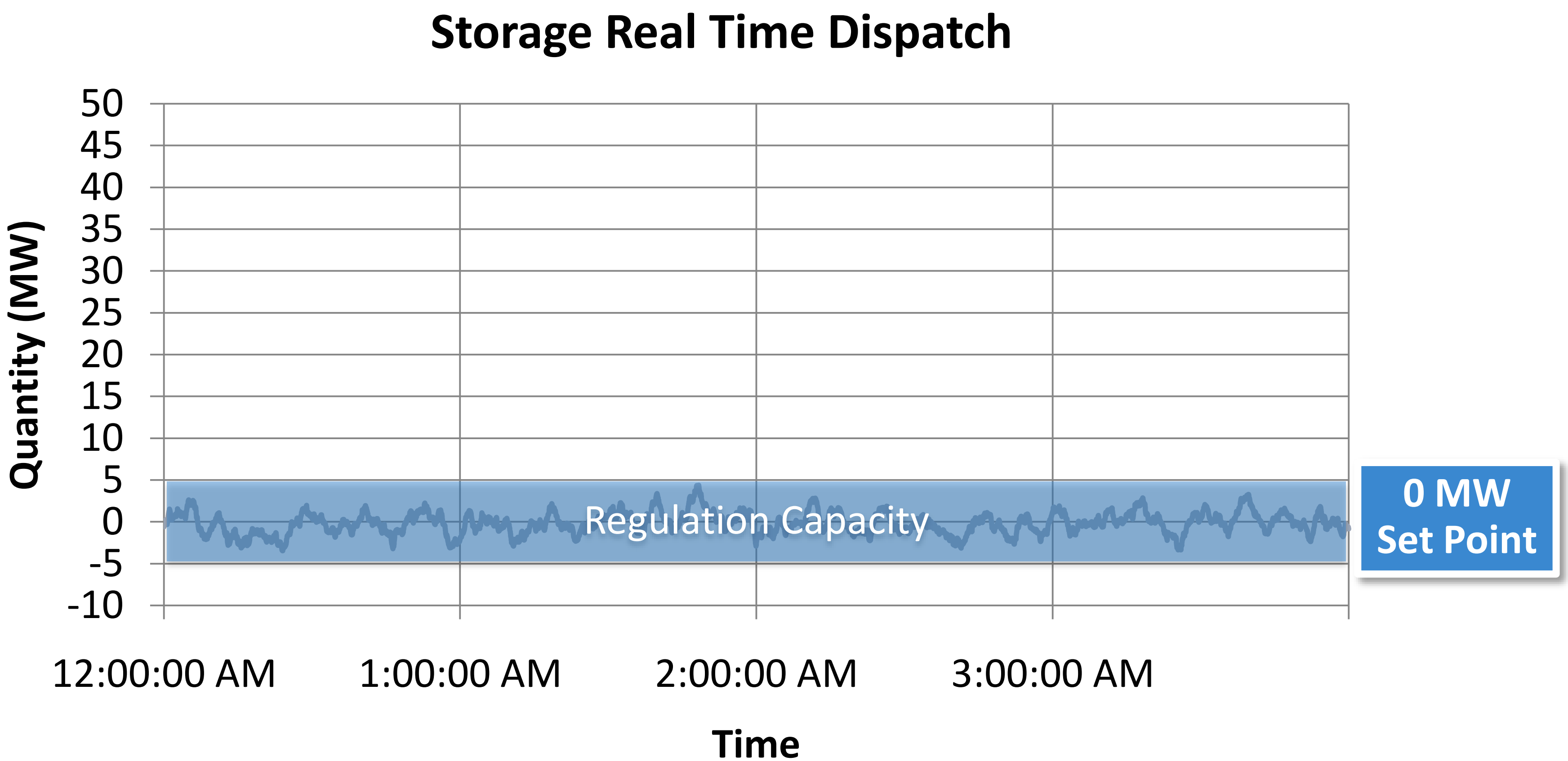
Frequency Regulation from Generators

Revenue = Freq. Reg. Capacity + Hourly Energy "Block"



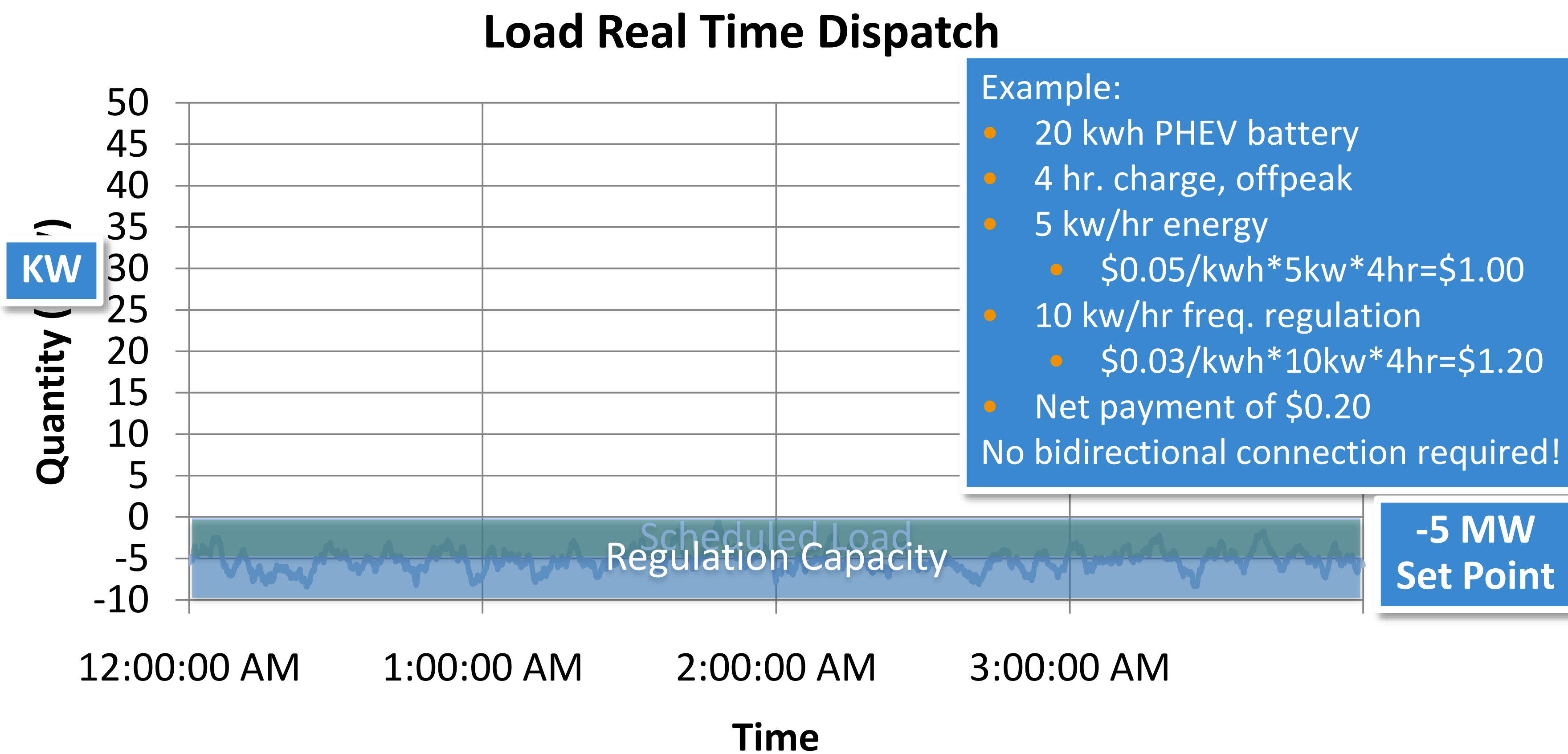
Frequency Regulation from Storage

Revenue = Freq. Reg. Capacity



Frequency Regulation from Loads

Net Revenue = Freq. Reg. Capacity – Hourly Energy “Block”



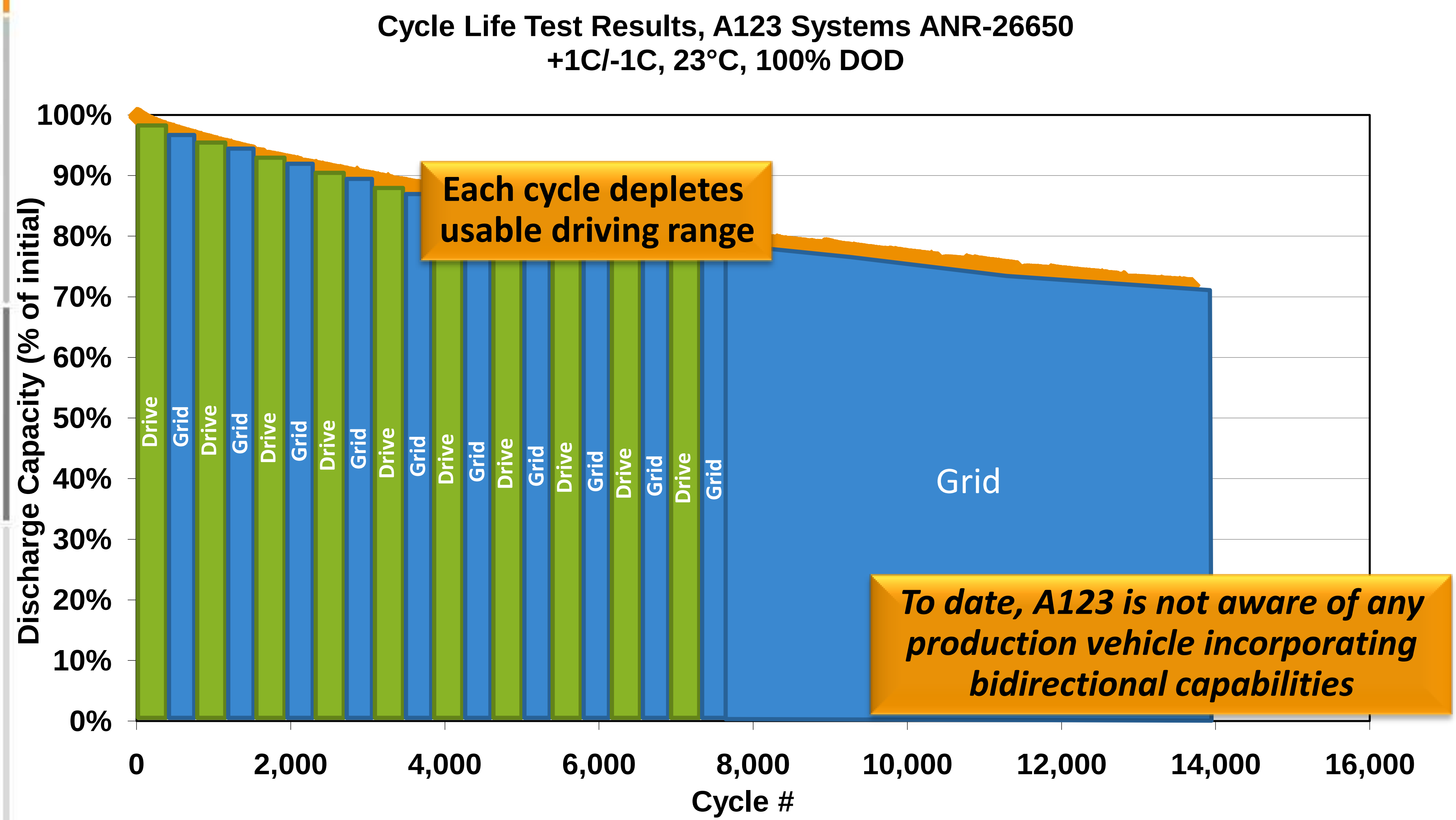
Example:
- 20 kwh PHEV battery
- 4 hr. charge, offpeak
- 5 kw/hr energy
  - $0.05/kwh*5kw*4hr=$1.00
- 10 kw/hr freq. regulation
  - $0.03/kwh*10kw*4hr=$1.20
- Net payment of $0.20

No bidirectional connection required!

Life

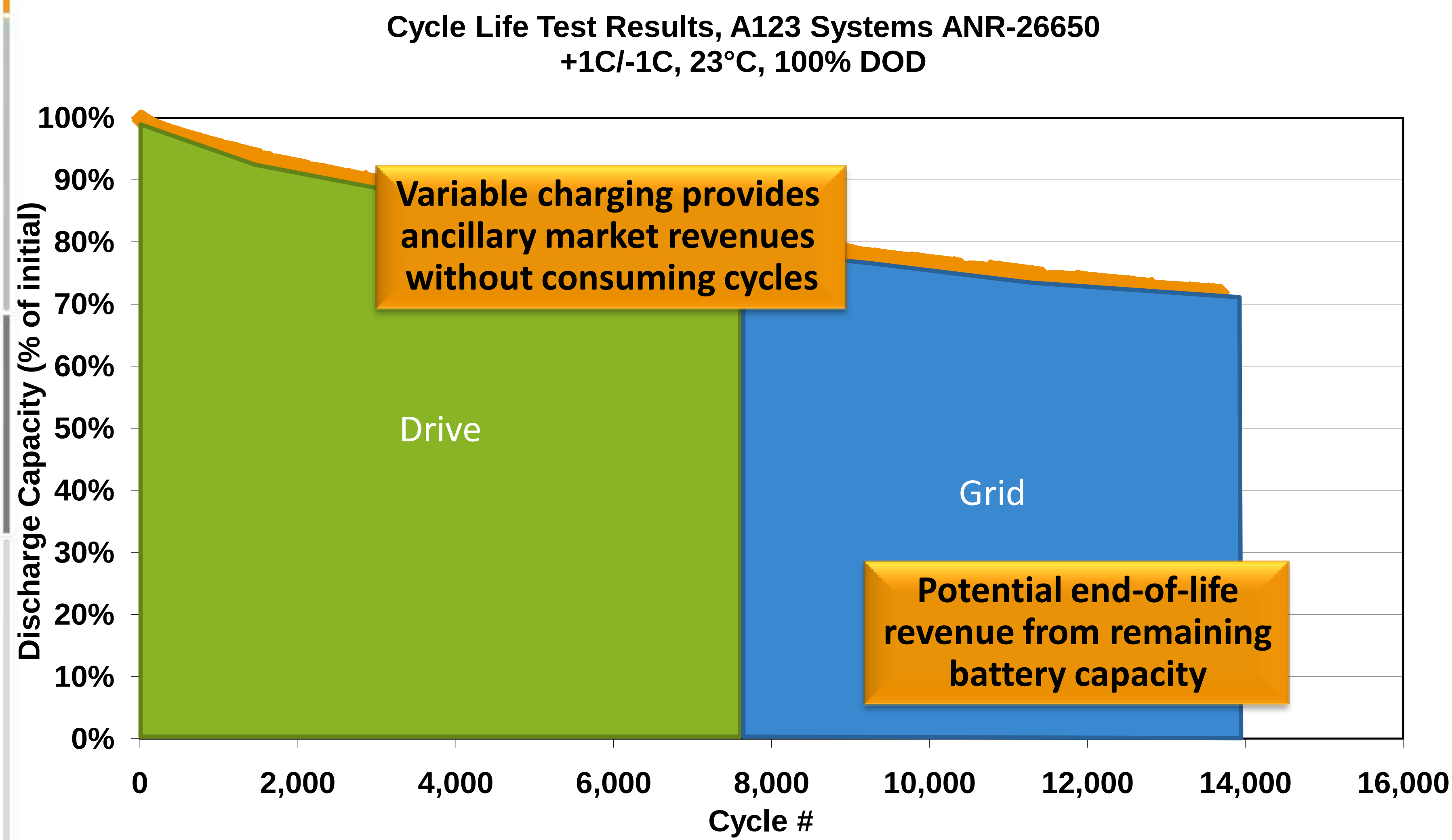
Capacity Uses: V2G vs. Second Life

A123 SYSTEMS



Capacity Uses: V2G vs. Second Life

Life



Business Case Comparison

Minimal incremental benefit from bi-directional flows

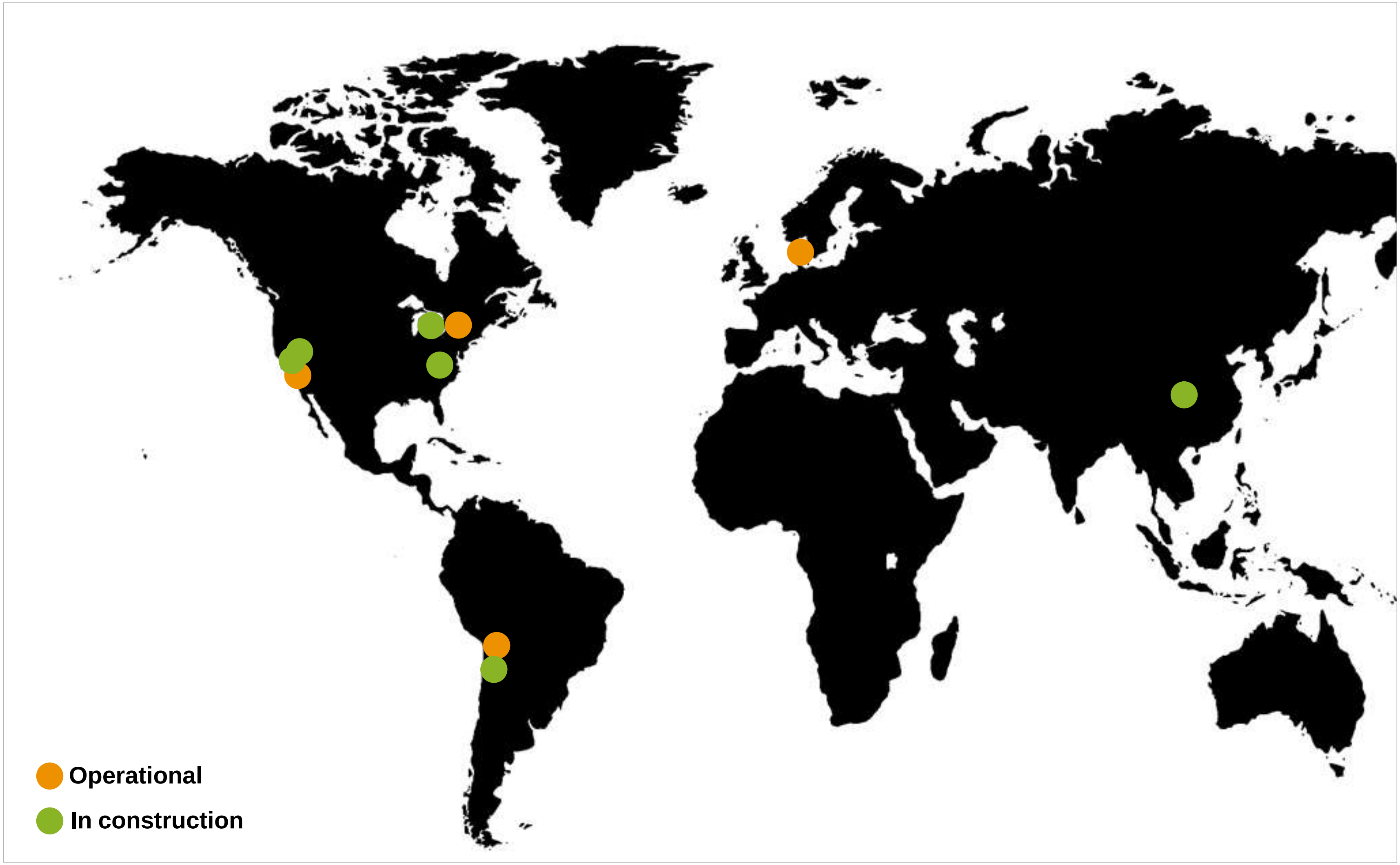
Highest-valued applications for today's standalone energy storage projects

	Frequency Regulation	Renewables Ramp Management	Spinning Reserve	Energy/Peak Shaving	Capacity
Steady State Charging	No	No	No	Partial (with dyna pricing)	
Variable Rate Charging	Yes	Yes	Yes	Partial (no arbitrage)	Partial
Bidirectional Flows	Yes	Yes	Yes	Yes (but faster battery life reduction)	Yes (but faster battery life reduction)

Likely sweet spot for near-term electric vehicles

A123 Selected Grid Deployments Worldwide

Over 40MW in service today



Conclusion

Full V2G may not be necessary

- Ancillary services (AS) provide sufficient revenue to spur commercial standalone storage projects
  - Frequency regulation (example of actual revenues)
  - Spinning reserves
  - Renewable ramp management
- Charge-only operation maximizes useful driving range
- EVs with variable charging can access AS markets with existing policy and market rules (EV acts like DR)
- Variable-rate charging likely to optimize vehicle performance and cost

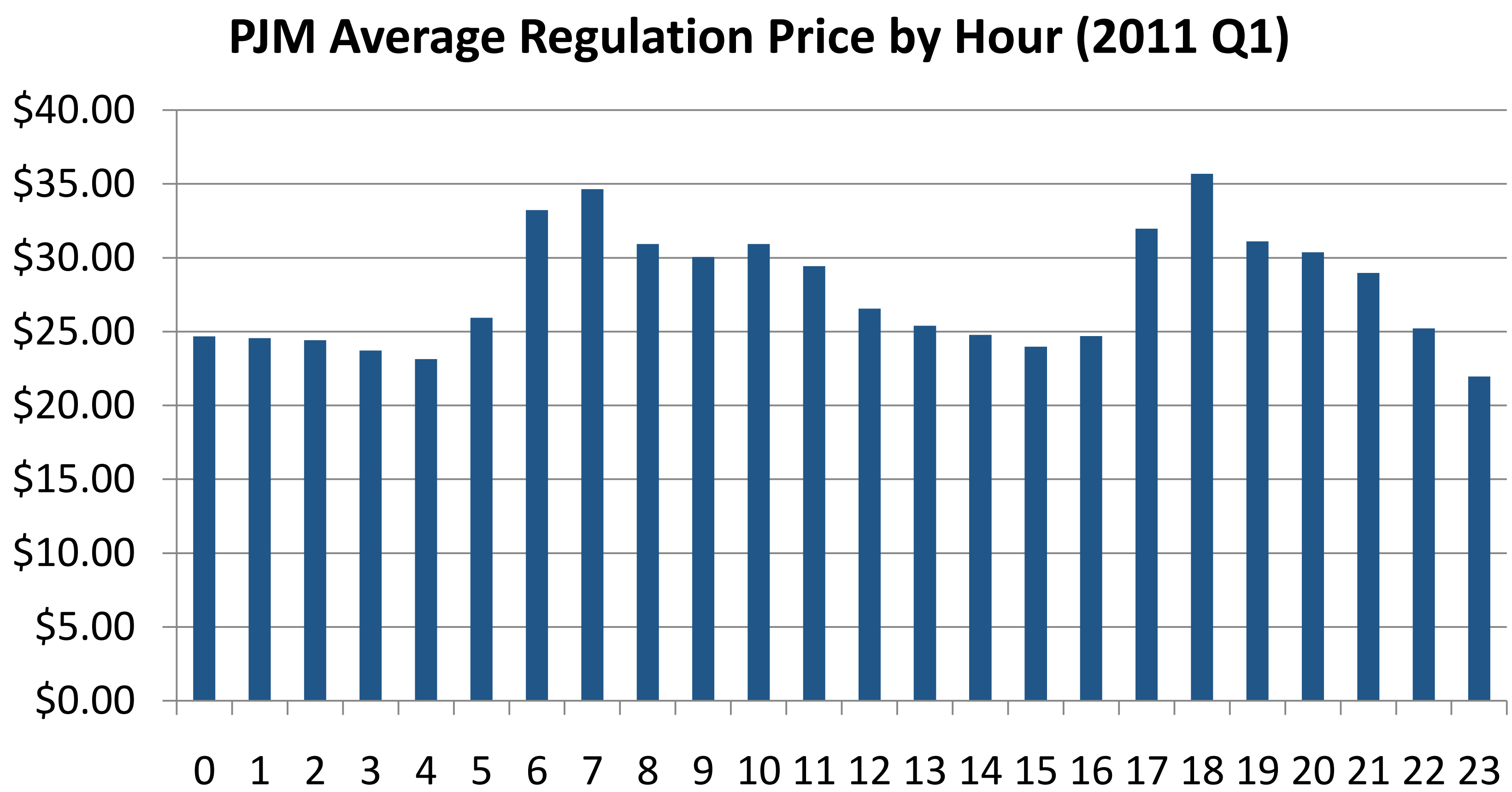
Thanks!

Eric Hsieh

ehsieh@a132systems.com

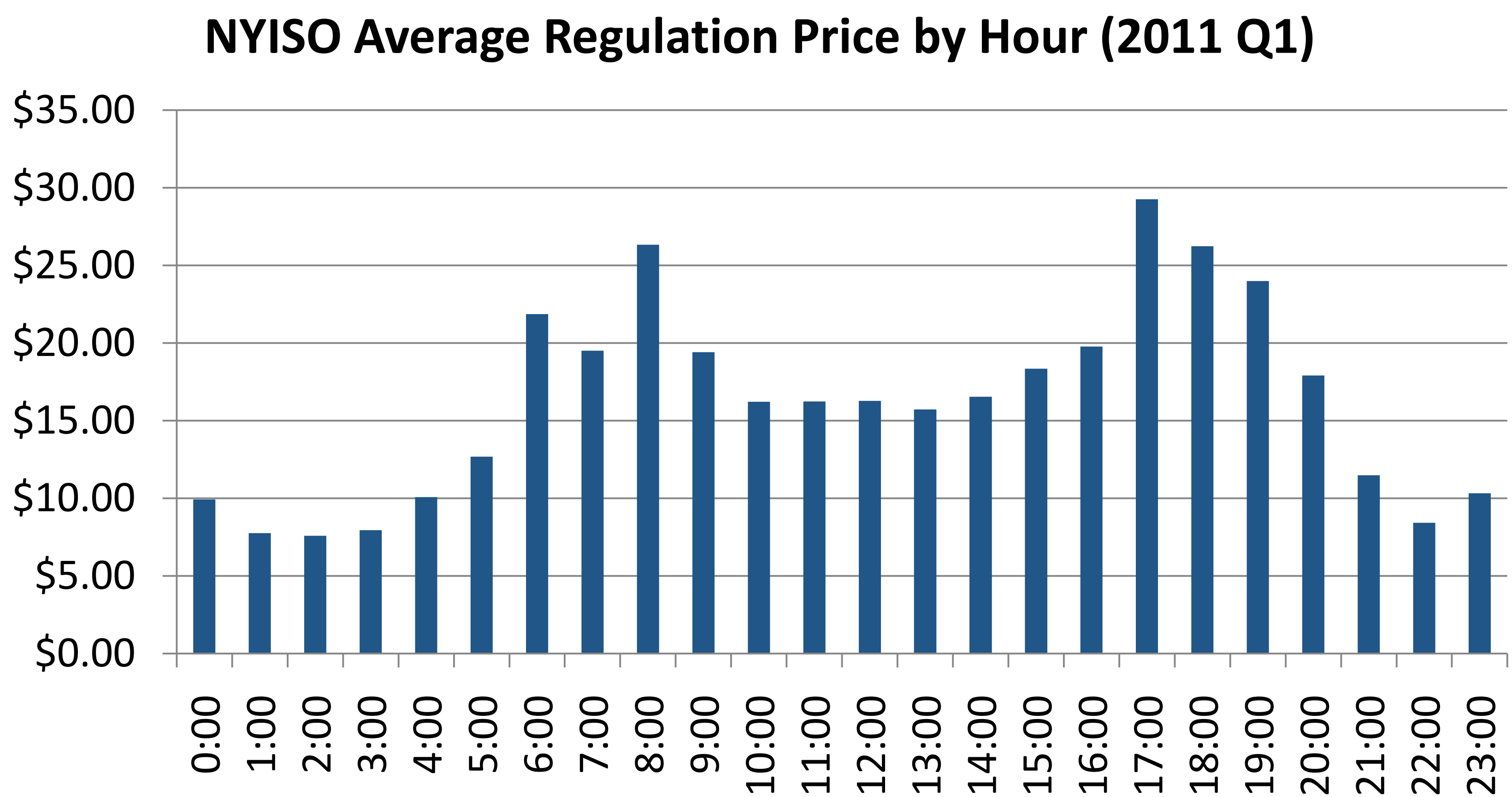
Hourly Regulation Prices

Highest value during morning and afternoon ramps



Hourly Regulation Prices

Highest value during morning and afternoon ramps



3) PCS Architectures for PEV as Storage

Session 3.2

Miles

Inverger Technology

Kathryn Miles

Eetrex Incorporated

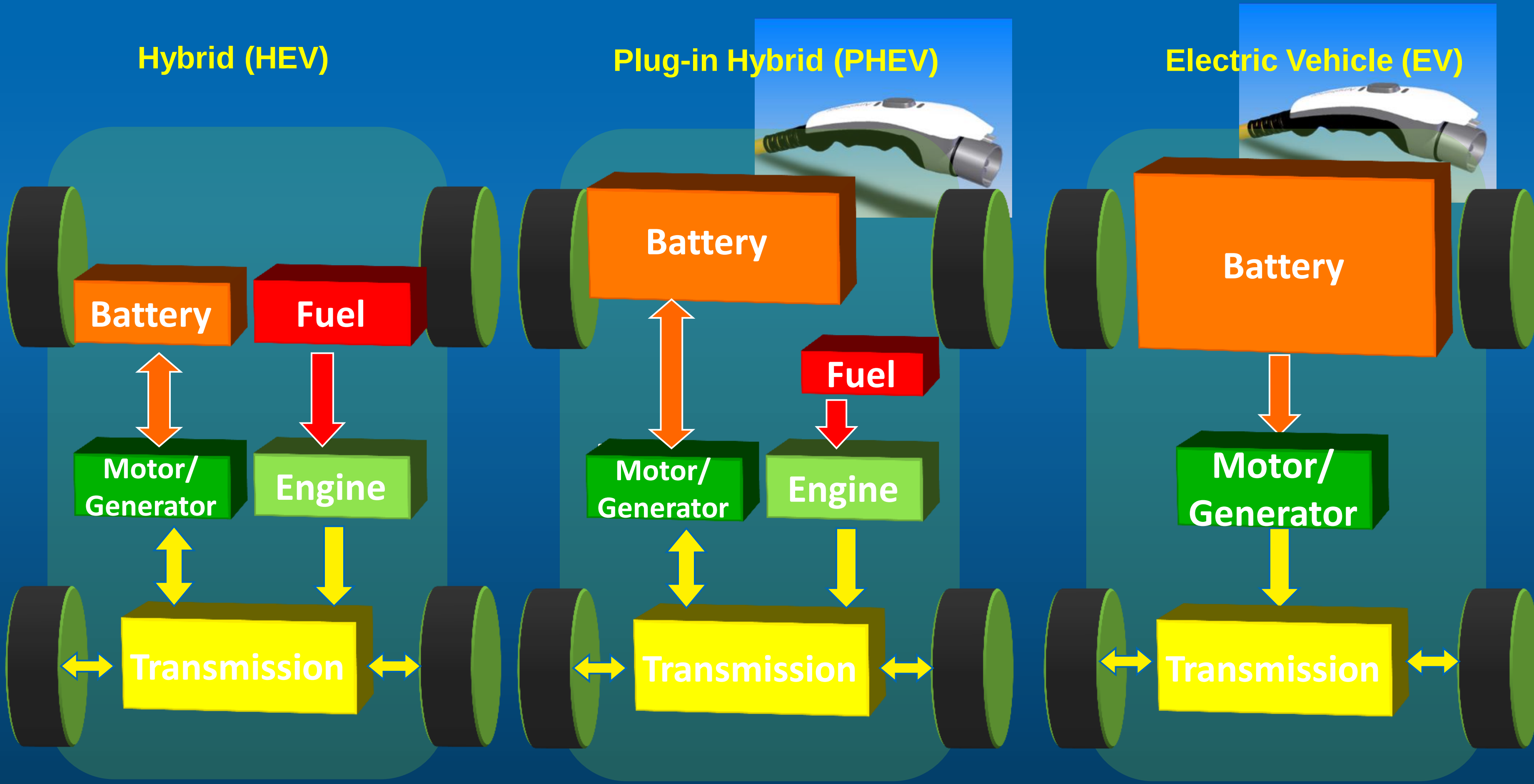
Energy Efficient Transportation Technologies

Eetrex Incorporated

- Xcel Energy's Utility Innovation partner in SmartGrid City
- Vehicle-to-Grid (V2G) Technology Leader (InvergerTM)
- Escape PHEV systems, CARB Certified, FMVSS
- Prius PHEV systems
- Core Battery Technologies
- Staff of 30 in 5,900 ft2 in Boulder, CO, founded in 2006
- Received two grants from the Colorado Governor’s Energy Office
- 56 PHEV Conversions to date over 650,000 miles
- Manufacturing Partner is Methode Electronics Inc., (MEI)

EEtrex
Energy Efficient Transportation Technologies

Electrification



Energy Efficient Transportation Technologies

Adding The Plug Opens Possibilities

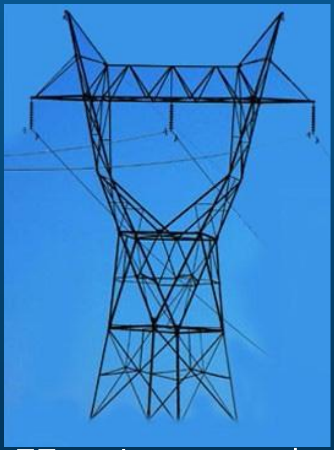
- Remote Power
- Mobile Power
- Smart Grid Power
- Independent Power
- Quiet Power

Inverger™

- Bi-directional battery charger/inverter
- Intelligent Charger uses Wind/Solar to Charge

Mobile, Distributed Power

- V2H or V2W
  - **Turn vehicle into clean and quiet generator, powering "critical" home/work components for 2+ days**
  - **Strong interest from vehicle OEM's**
- V2X
  - **Vehicle is "mobile power"**
  - **On-demand energy, anywhere**
- V2G
  - **Storage for renewable**
  - **Provide regulation**



EEtrex
Energy Efficient Transportation Technologies

Inverger™ Specs

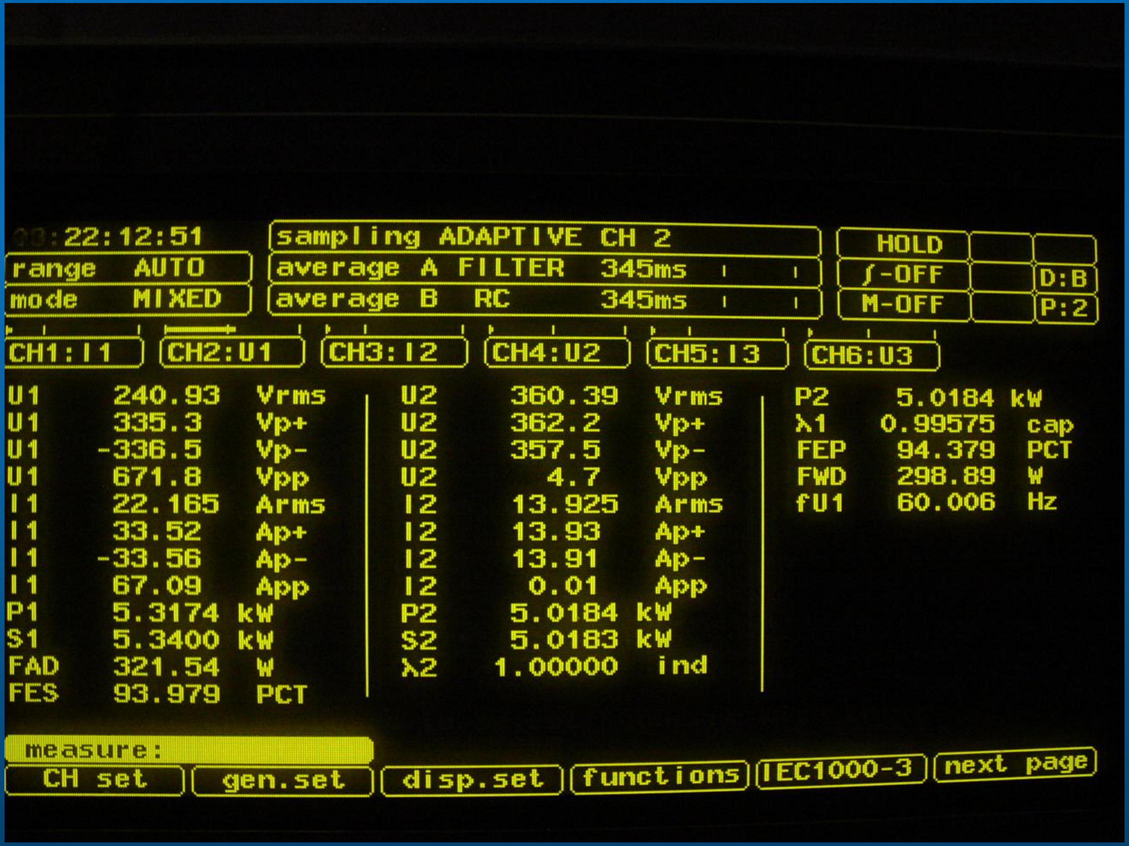
AC Connection
- 6.6 kW
- Voltage Range: 110 – 240 Volts
- Current Range: 12 – 30 Amps
- Ground Fault Outlet

AC Connector – Per Customer
- E.g. 110/240V, 50A, 3-Pole,
- 4-wire, Grounding, Locking, Corrosion Resistant

DC Connection
- Voltage Range: 100 – 400 Volts
- Current Set by AC Connection

Communication
- CAN Bus
- Cellular Modem

Inverger™: Charging at 5kW



Charging Test Data at 5kW

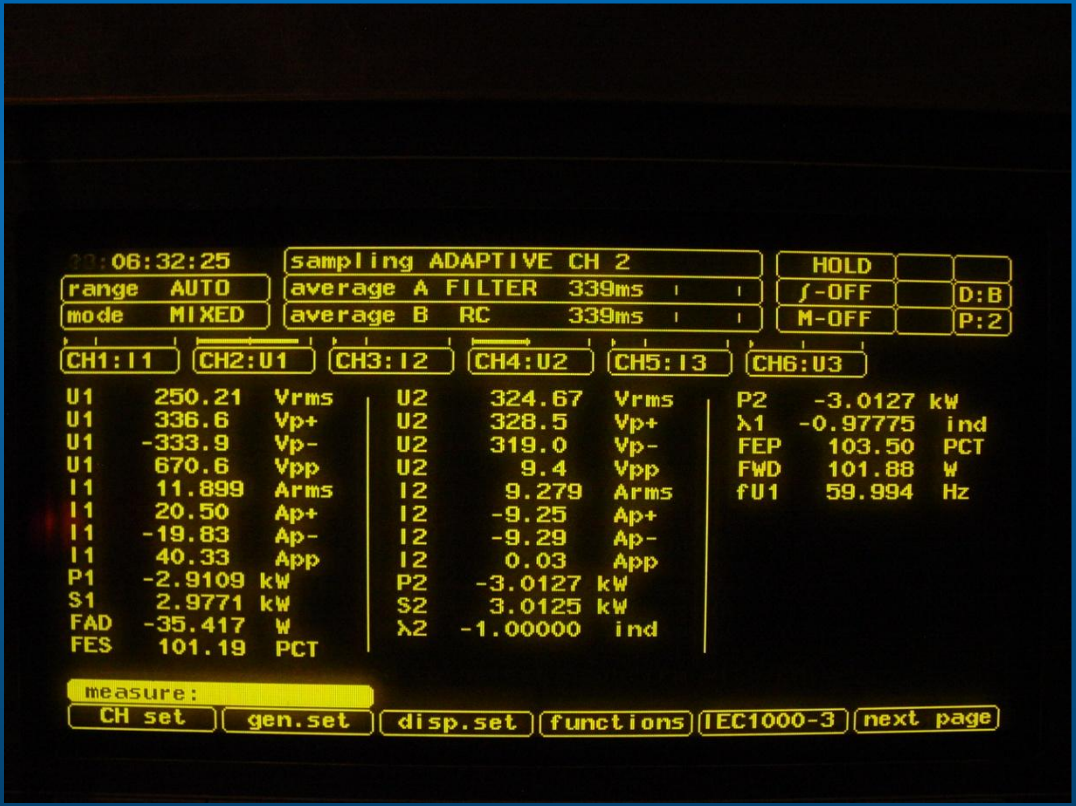
Charge Mode Power Analysis:
5Kw output
.995 PF line to battery
94.4% Conversion efficiency line to battery
298.89 watts dissipation

AC Line Input:
240.93 Line VAC
5.3174Kw

DC Charge Output:
Battery voltage (controlled load)
360.39 vdc
Charge current 13.925 adc
Output Wattage 5.0184 Kw

Energy Efficient Transportation Technologies

Inverger™: Discharging at 3kW



Discharging Test Data at 3kW

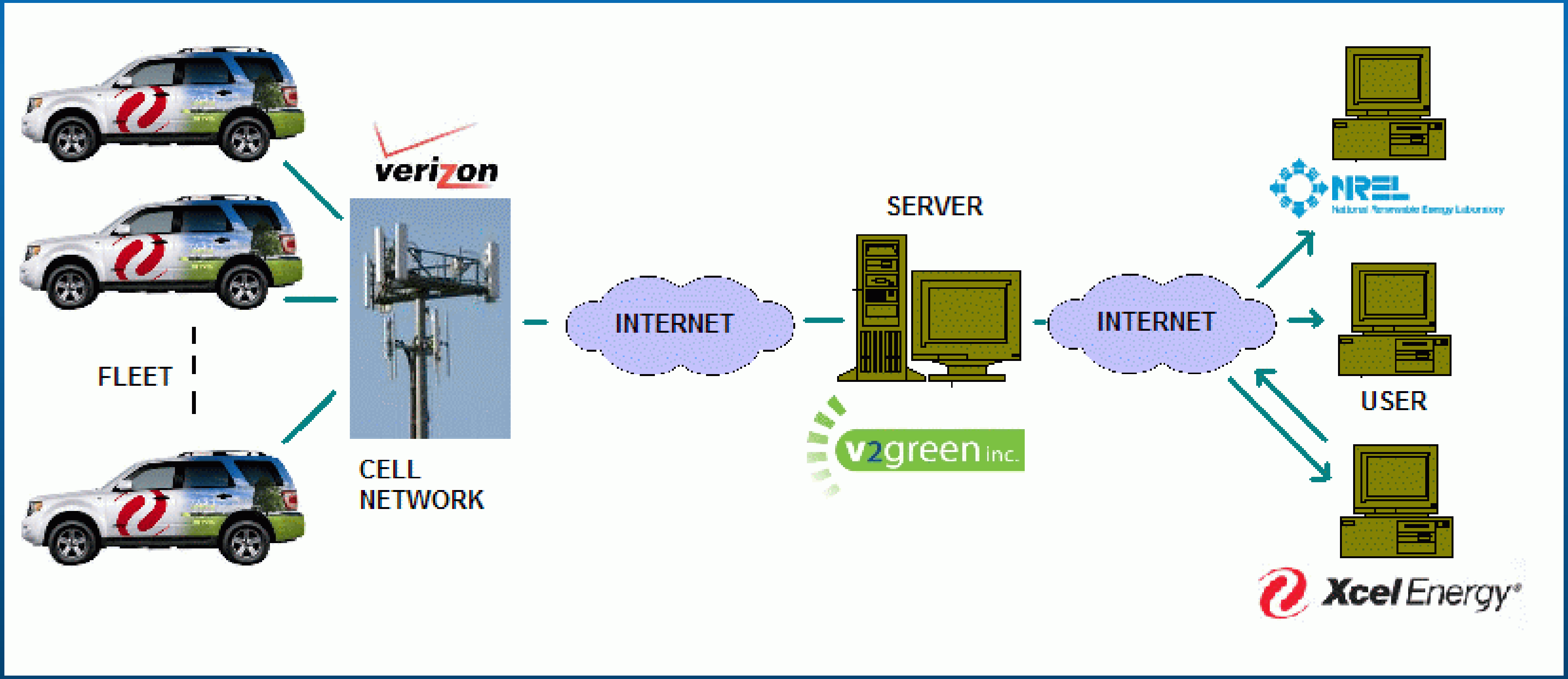
Discharge Mode Power Analysis:
3Kw Battery source power
.977 Output PF
96.50 Conversion efficiency battery to line
101.88 watts dissipation

DC Input:
3.012 Kw
324.67 DC battery voltage
9.27 Amps DC RMS battery current
.

AC Line output:
250.21 Line VAC
.977 PF
2.91 Delivered Kw
2.97 KVA

EEtrex Energy Efficient Transportation Technologies

Data Communications & Charge/Discharge Control



Florida Power and Light

GRIDPOINT

LOG OUT

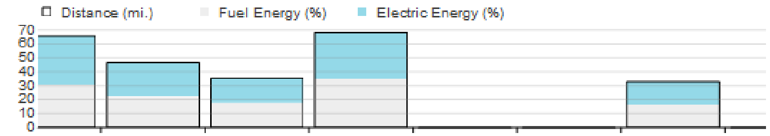
Vehicles

- FP&L 1127
- FP&L 1400
- FP&L 1460
- FP&L 1461
- FPL Escape 2311
- FPL Mariner 2825

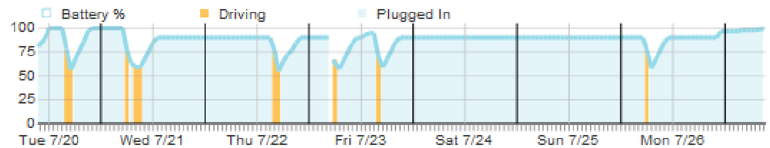
FPL Escape 2311 : Ford Escape Hybrid 4WD 2004-2007 with HybridsPlus kit

State: Plugged In
Fuel Level: 74%
Battery Level: 99%
Location: FP&L Office
AC Power: 0.0kW

Travel by Fuel Source



Battery Level



Performance Report | Timeline | Trips | Charge Sessions

Detailed Statistics

	Today	Last 7 Days	Last 30 Days
Driving			
Trips	0	12	55
Time	0 m	4 h 18 m	21 h 59 m
Distance (mi.)	0.0	183.1	985.5
Fuel (gal.)	0.0	3.6	20.4
DC Energy (kWh)	0.0	-28.9	-125.5
Est. Cost ($)	$0.00	$18.53	$99.46
CO_2e (lbs.)	0.0	85.0	481.1
Charging			
Sessions	1	6	29
Connect Time	1 d 2 h 34 m	5 d 22 h 2 m	24 d 23 h 26 m
Connect Score	279%	95%	88%
AC Energy (kWh)	6.5	32.5	147.6

Fleet Comparision

	Today	Last 7 Days	Last 30 Days
MPG			
FPL Escape 2311	0.0	50.9	48.3
Fleet	53.4	51.9	47.2
National Average	19.8	19.8	19.8
CO_2e (lbs.) / mi.			
FPL Escape 2311	0.0	0.5	0.5
Fleet	0.4	0.5	0.5
National Average	1.2	1.2	1.2
$ / mi.			
FPL Escape 2311	$0.00	$0.10	$0.10
Fleet	$0.10	$0.10	$0.10
National Average	$0.20	$0.20	$0.20

Help | Account Settings |

Done   Internet | Protected Mode: On   100%

Thank You

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3) PCS Architectures for PEV as Storage

Session 3.2
Lacobelli

AZD
AZURE DYNAMICS
part of the solution

AZD Power Electronics for Hybrid Vehicles

June 13, 2011

Agenda

- Azure Dynamics Background
- P/HEV and EV Products
  - P/HEV Balance
  - Transit Connect Electric
  - LEEP Lift
- Power Electronics
- V2G considerations

Who is Azure Dynamics?

- > **Azure Dynamics is an industry leader in hybrid electric and electric powertrain solutions in the commercial vehicle segment**
- > **~ 20 years in this industry**
- > **Locations in Detroit, Boston, Vancouver & UK (total employees ~ 160)**



Broad Range of Applications

PHEV Balance Hybrid

- 14 kWh Li-Ion battery (nominal = 346 V)
- Electric drive motor cont. power ~ 50 kW
- >20 mile electric range (blended)
- Acceleration rates within ~ 10% of stock veh.
- Level 1 & 2 Smart charging capability
- Charge time (240V) ~ 4 hours

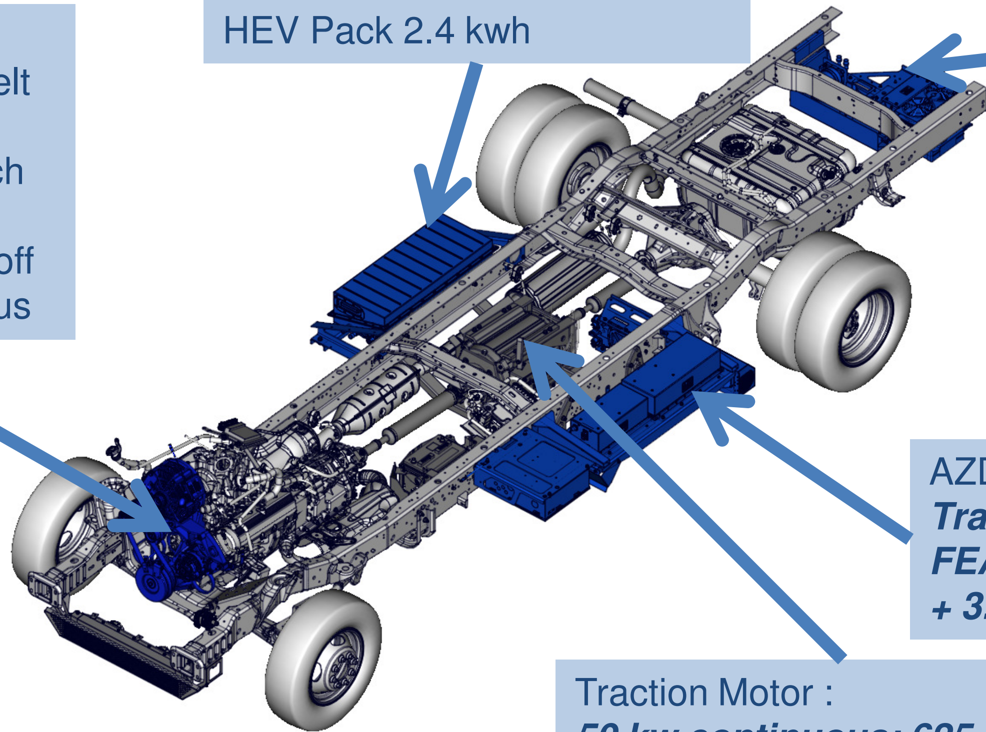
- **Azure's PHEV product offer the following features:**
  - Engine Idle Off
  - Urban Electric drive Performance
  - Electric launch assist (PHEV and HEV mode)
  - Regenerative braking
  - Electric A/C – chassis cab and body
  - Automatic conventional mode redundancy
  - Electric power steering and brake assist

2011 MY Balance Hybrid Technology

Advancements to AZD Industry Leading V8 Belt Starter Generator - integrated electric Clutch – motor can spin auxiliaries with Engine off - Approx 6 kw continuous

JCS Li Ion PHEV battery Pack
14 kwh
HEV Pack 2.4 kwh

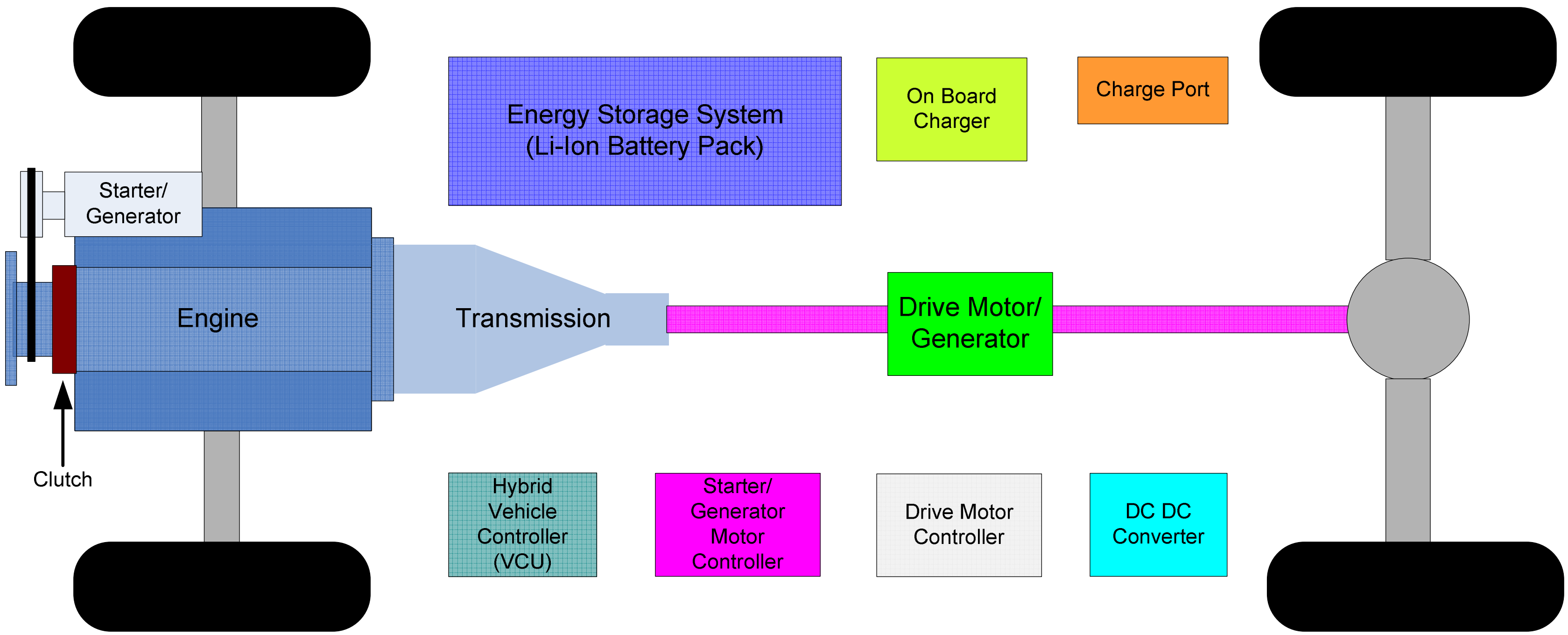
65,000 BTU Electric A/C compressor – AZD Force Drive inverter controlled (for Shuttle bus)



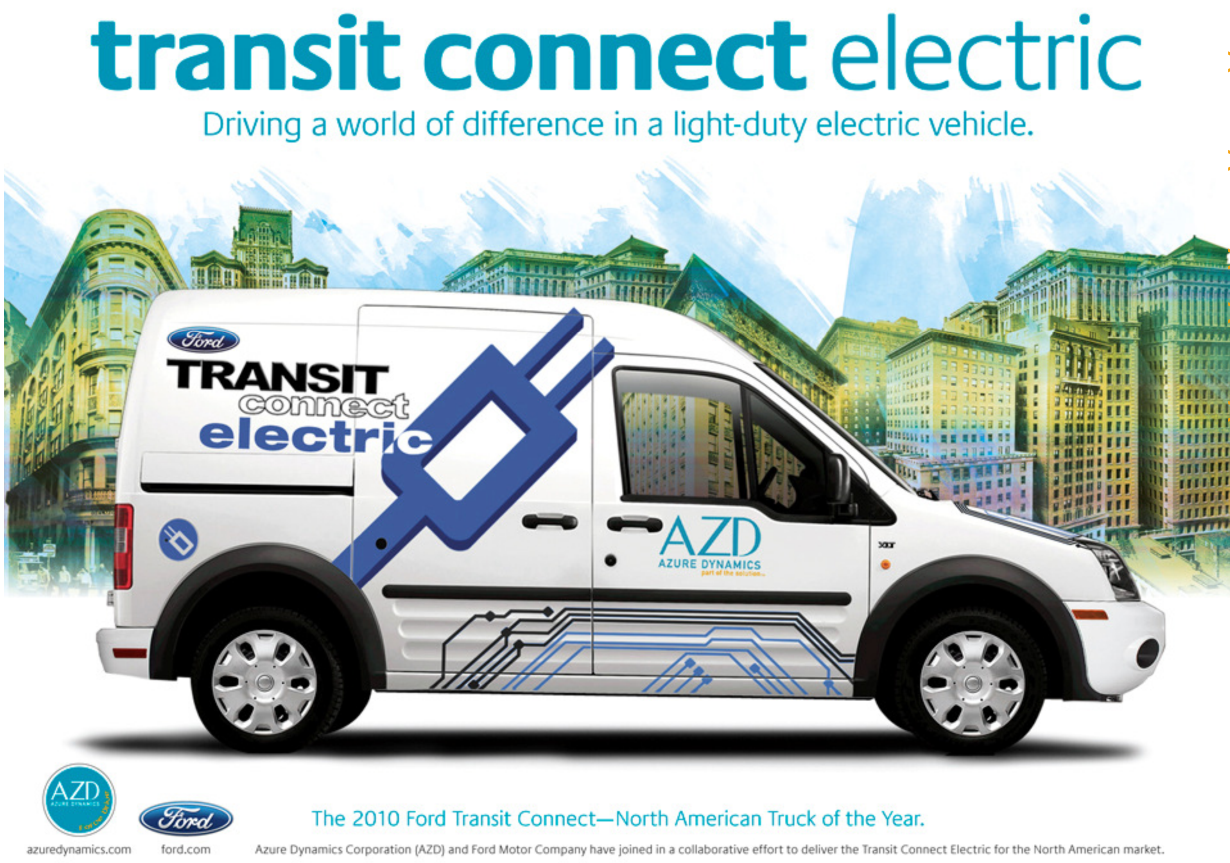
AZD Force Drive inverters:
Traction – (600 amp)
FEAD – (400 amp)
+ 3.3 kw charger

Traction Motor :
50 kw continuous; 625 nm peak torque

PHEV Balance

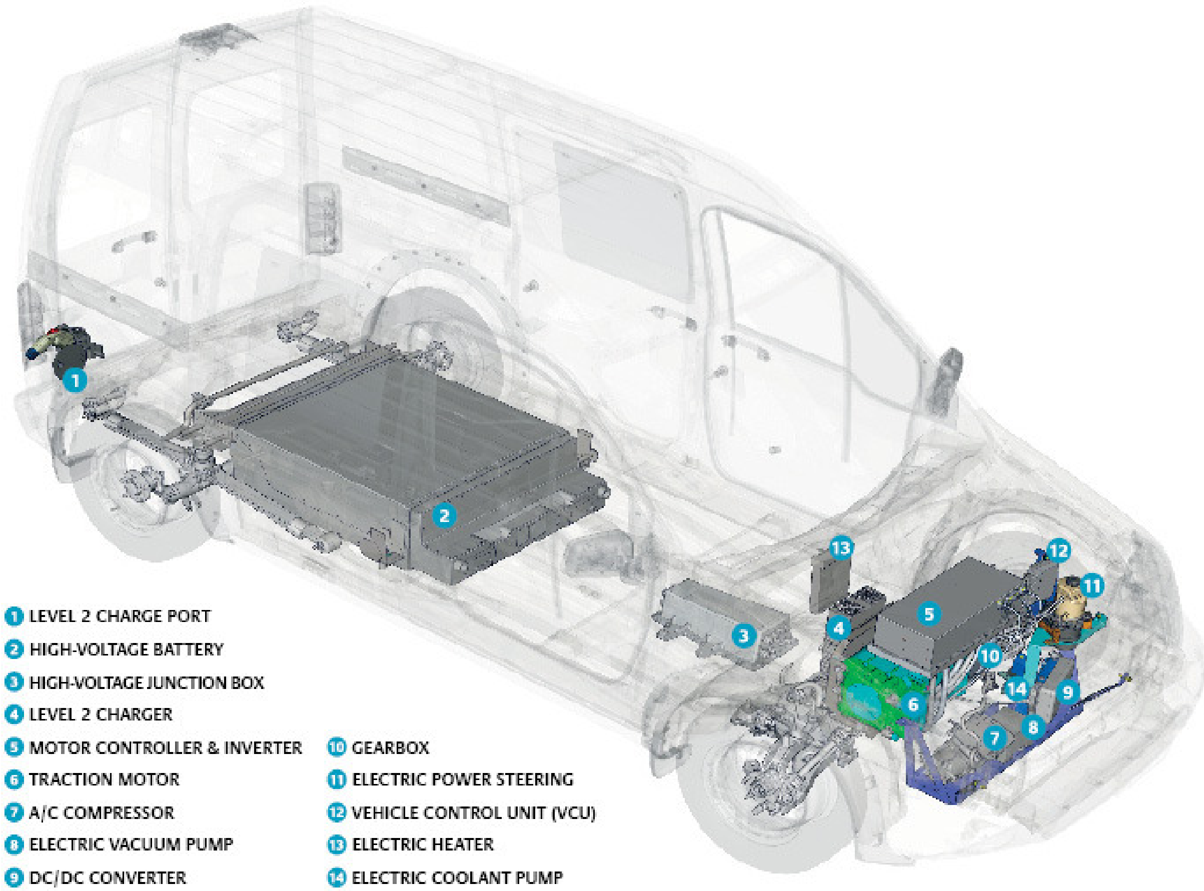


Transit Connect Electric

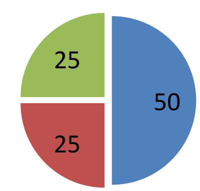


- 28 kWh Li-Ion battery (nominal = 346 V)
- Electric drive motor cont. power ~ 57 kW
- 80 mile electric range UDDS
- Level 1 & 2 Smart charging capability
- Charge time (240V/30A) ~ 8 hours

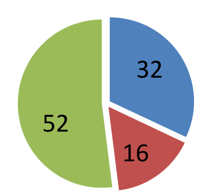
Lessons Learned – Ideal Platform for an EV



UDDS Energy Distribution



US06 Energy Distribution



LEEP Lift

System Benefits are:

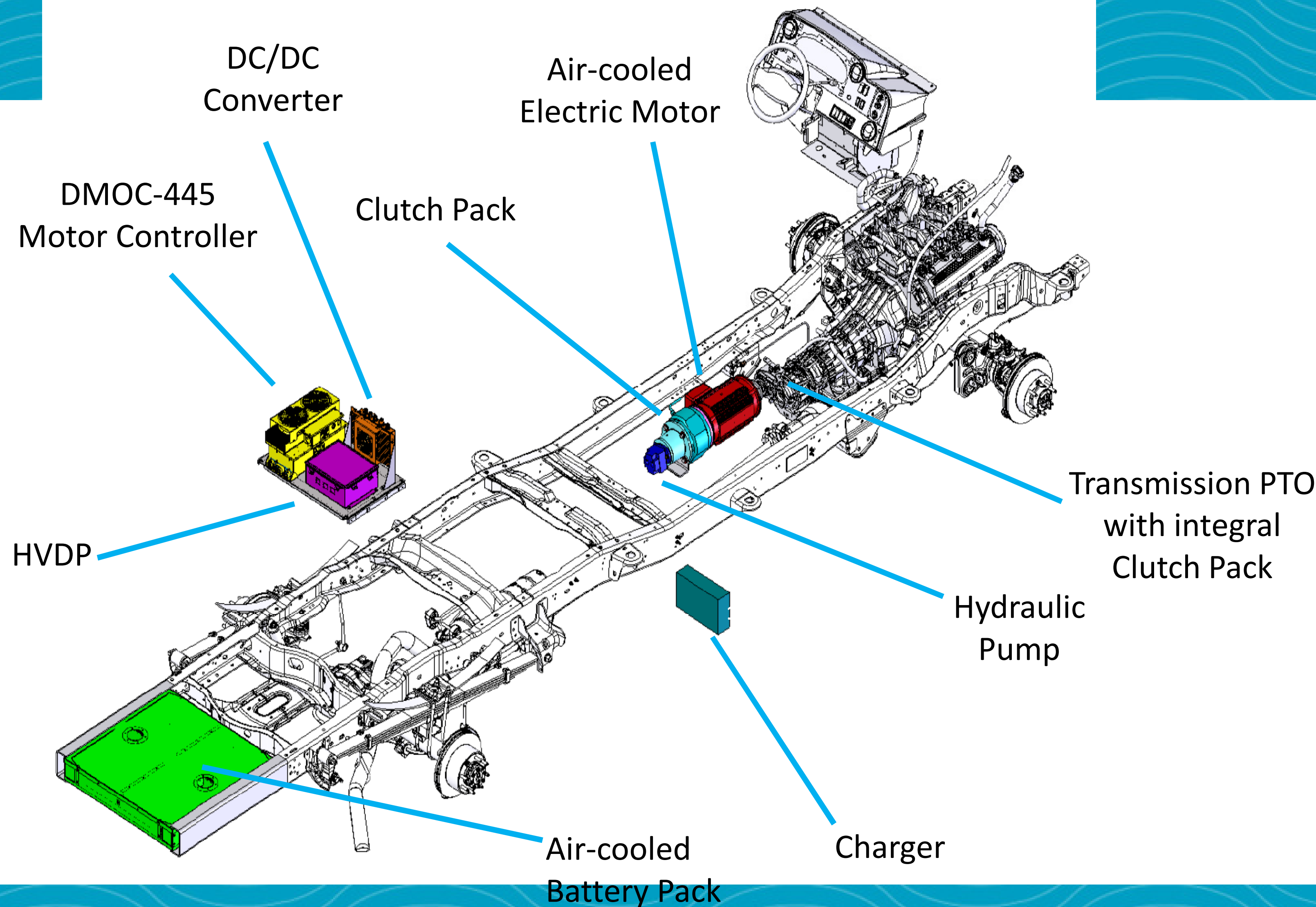
- Significant fuel and emissions savings
- Anti-idle compliance
- Engine-off boom operation
- Engine-off 12V DC Supply
- Reduced overall engine maintenance
- Excellent fault tolerance
- No-little impact to normal packaging space
- Modest impact on payload

Options

- Plug-in recharging capable
- 2 kVA 115 VAC export Power
- 750 Watt 12V Blocks of power

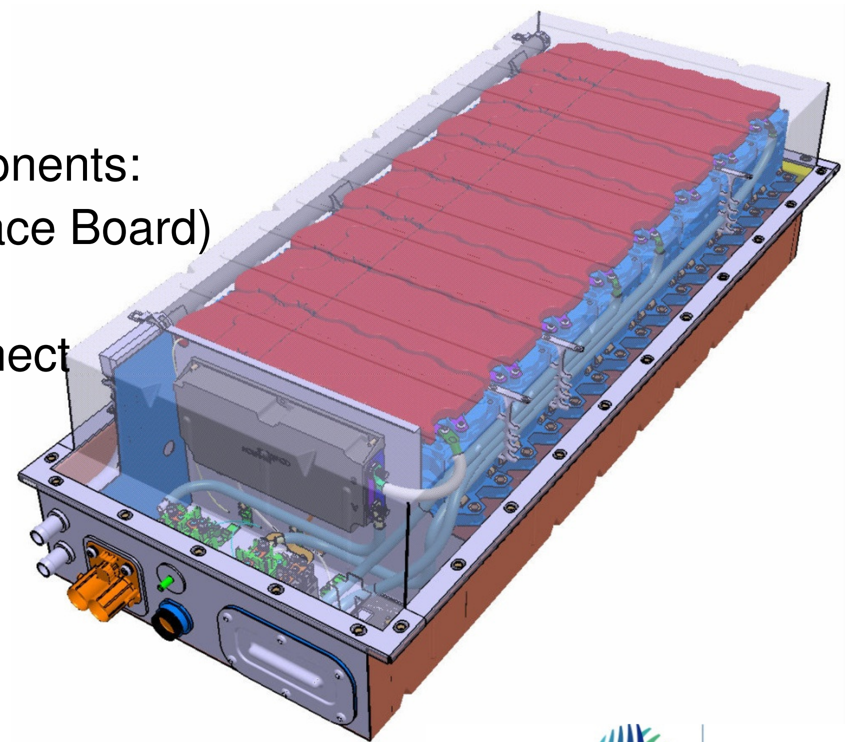
AZURE DYNAMICS LEEP Lift

LEEP Lift System Implementation



PHEV Balance Hybrid Pack

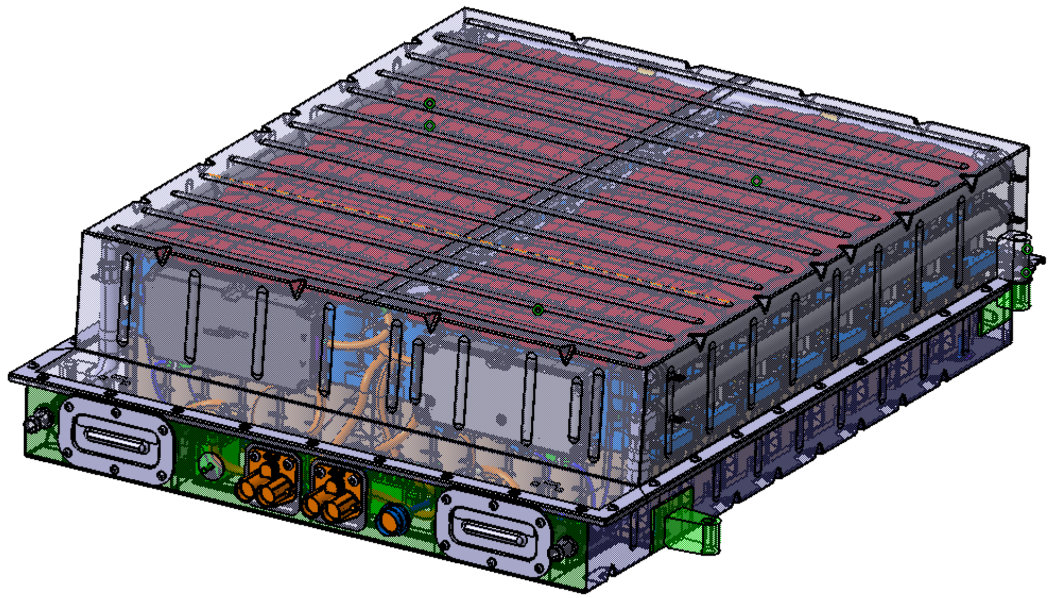
- Liquid Cooled,14 kWh system
- 346 V nominal
- 96 x VL41M cells
- Unique housing utilizing carry-over components:
  - Core Electronics (BMU, CSC and Trace Board)
  - EM12B Module; Coolant Manifolds
  - HV / LV Connectors; Service Disconnect
  - Contactors; Pre-charge Resistor



Johnson Controls | saft

Transit Connect Electric Pack

- Liquid Cooled, 28 kWh system
- 192 x VL41M cells
- 2 parallel strings of 96 cells
- 346 V nominal
- Unique housing utilizing carry-over components:
  - Core Electronics (BMU, CSC and Trace Board)
  - EM12B Module; Coolant Manifolds
  - HV / LV Connectors; Service Disconnect
  - Contactors; Pre-charge Resistor
- **DESIGN LIFE – 10 Years; 120,000 Miles**



Johnson Controls | SAFT

Flagship Components

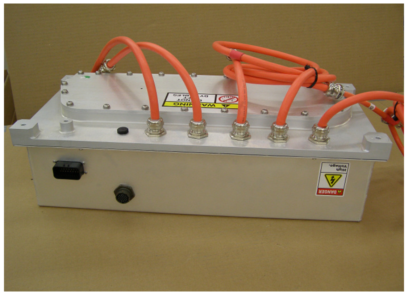
Our components are based on over 15 years of development and field experience

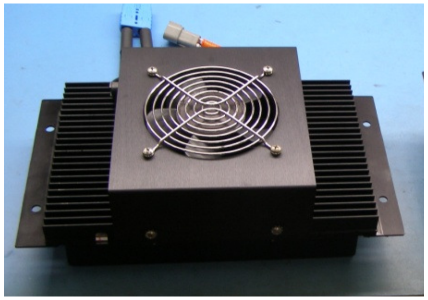
> Digital Motor Controllers (DMOC)

- Ground-up design
- Three power levels (120 kVA, 80 kVA, 20 kVA)
- All digital field oriented control
- Space-vector PWM
- Thermal management (air and liquid cooled)
- Over and under-voltage protection
- Three level over-current protection

> DC-DC Converters

- Voltage source and battery charging
- Isolated power transfer

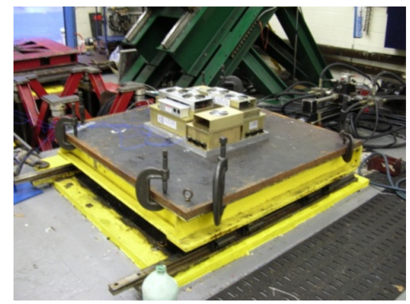


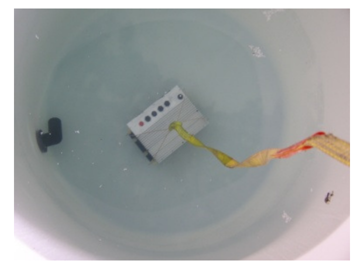


Power Electronics

Our latest generation components are designed to meet the stringent requirements of commercial fleets.

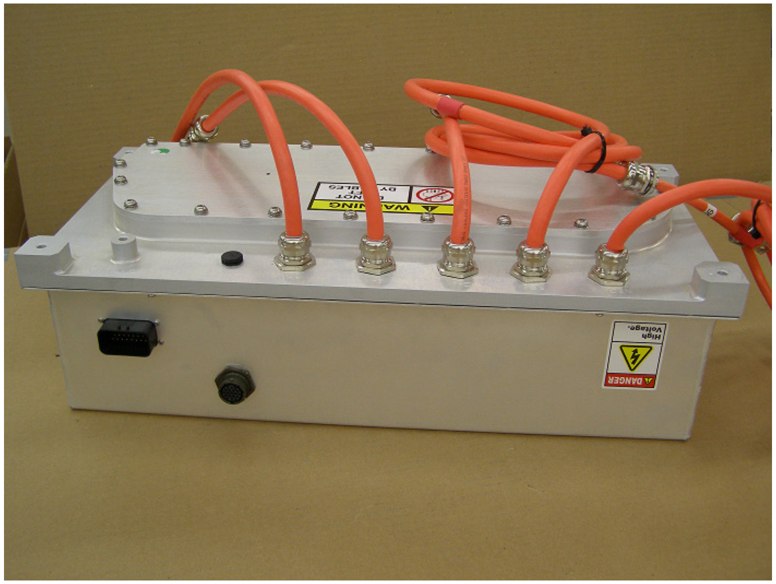
- Life: 20,000 hours
- EMC:
  - EU specifications 2004/104/EC
  - Ford ES-XW7T-1A278-AC
  - GM3097
- IP65/IP67
- Chemical: SAE J1455
- Vibration: ISO 16750-3





Gen-II Characteristics

- Max AC current: 420 Arms
- Max DC voltage: 400 VDC
- Coolant: 55C @ 10l/min
- Weight: 21 kg
- Volume: 25 L
- AC Motor Control Algorithms
- Derivability Algorithms
- CAN Interface
- UDS for Diagnostics



DMOC645-LC

Gen-III Drive Characteristics

- Nominal peak power: 150 kW
- Max voltage (non-operating): 550 V – up from 450V
- Max operating voltage: 450V – up from 400 V
- Max output current: 420 Arms - unchanged
- Rated current: 200 Arms, at 10l, 65C coolant – up from 55C
- Weight: 15 kg – down from 21 kg (DOE: 12 kW/kg)
- Volume: 10 L – down from 25 L (DOE: 12 kW/L)
- Cost: 40% reduction
- ISO 26262 compliant (Functional Safety)
- Complete Ford EMC compliance

V2G Considerations

- V2G components must be robust to meet on vehicle environmental; EMC; Safety; performance requirements
- P/HEV and EV's are already cost challenged – V2G must provide economic return
- What is the best way to integrate – standalone or with drive inverter & motor? Some level of integration is preferred for lower cost, weight and robustness
- What is the new design life requirements for all affected components – already a 20,000 hr requirement without considering V2G?
- Vehicle availability for EV's – when to charge/discharge?
- Standardized communications and smart grid readiness
- How will battery life be affected?

Lessons Learned – Opportunities to Support Wider EV Adoption

EV range and infrastructure continue to limit widespread adoption

- There is no single answer => focus on all of the following areas will improve EV adoption:
  - Battery advancements
  - Vehicle and electric drive efficiency gains
  - Fast charging infrastructure -> mitigate need of on-board energy
  - V2G and Smart charging -> improve Cost of ownership
  - Range extender and PHEV options

Q & A

3) PCS Architectures for PEV as Storage

Session 3.2

Alexander

Current-Modulation Electronic Power Converters

NIST/DOD Workshop
Power Conditioning System Architectures
for Plugin-Vehicle Fleet as Grid Storage
13 June 2011

Bill Alexander
CEO, CTO, and founder
Bill.Alexander@IdealPowerConverters.com

IDEAL POWER CONVERTERS

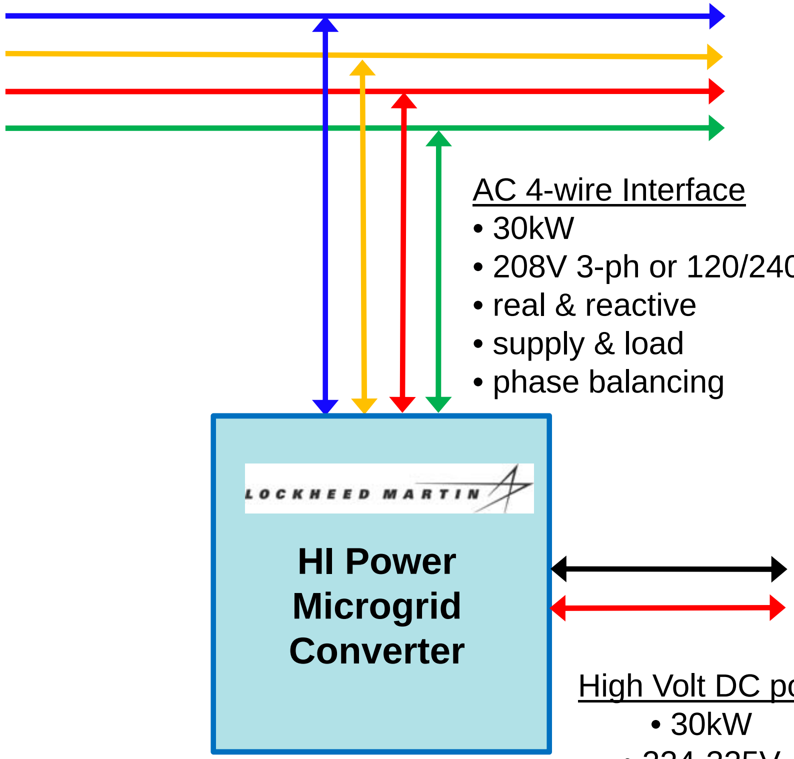
IDEAL POWER CONVERTERS

Hybrid Intelligent Power
for Forward Operating Bases

AC grid or generator(s)

Reduces diesel fuel requirements by up to 40%

208V AC Wye
4 wire, 3-phase, balance or unbalanced



Intelligent loads
- shedding
- prioritizing

AC 4-wire Interface
- 30kW
- 208V 3-ph or 120/240 1-ph
- real & reactive
- supply & load
- phase balancing

DC interface to:
- **Local batteries**
- **PV Array**
- **Asynchronous microgrids**

High Volt DC port
- 30kW
- 224-325V
- Bi-directional
- 22 lbs

IPC - develops HI Power Microgrid Converter, low level controls
Lockheed Martin – converter packaging, system controls, testing

Bidirectional
Battery Inverter/Charger

Applications

- **Stationary Batteries**
  - 30 kW, 480 VAC three phase 60 A
  - 0 to 700 volts DC
  - Bi-directional, power-to-grid

- **Vehicle Batteries**
  - Bidirectional Level 3 DC charger
  - Power-to-grid
  - Common mode isolated or full isolation

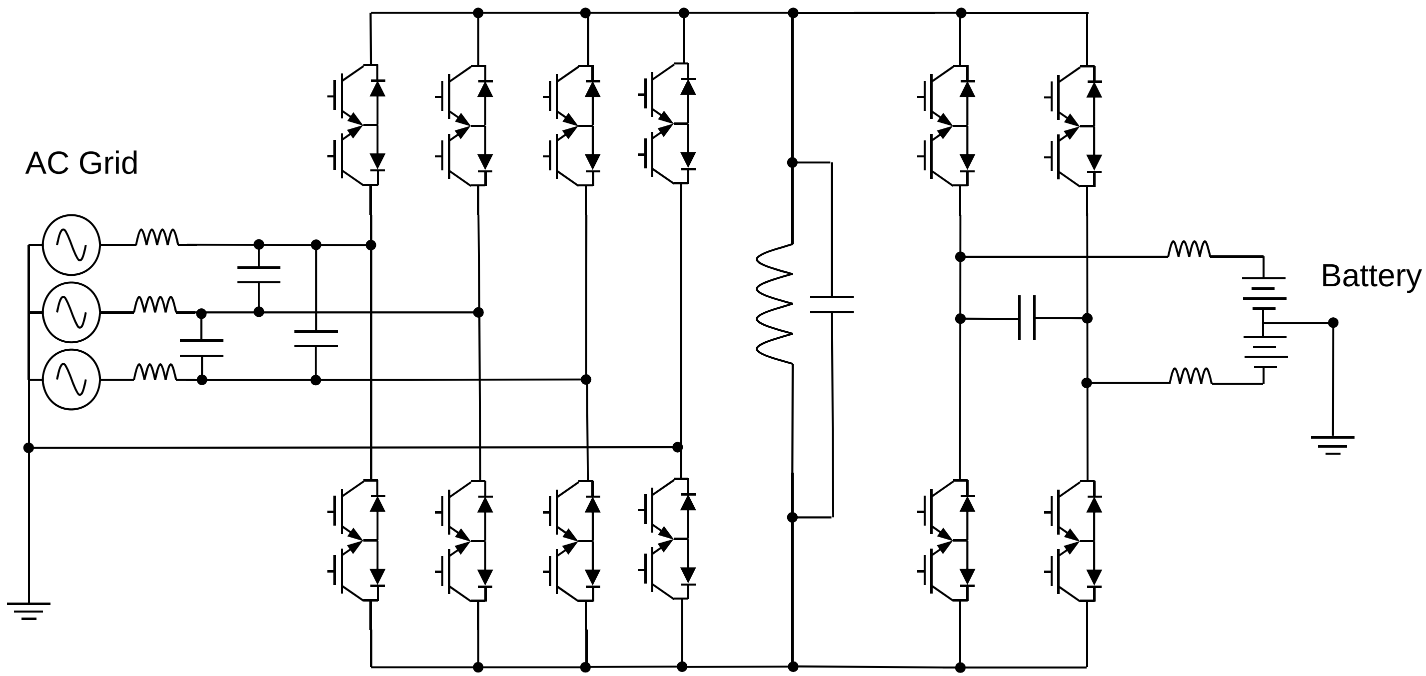
30kW 480VAC battery inverter
80lbs, wall-mount
97% efficiency

IDEAL POWER CONVERTERS

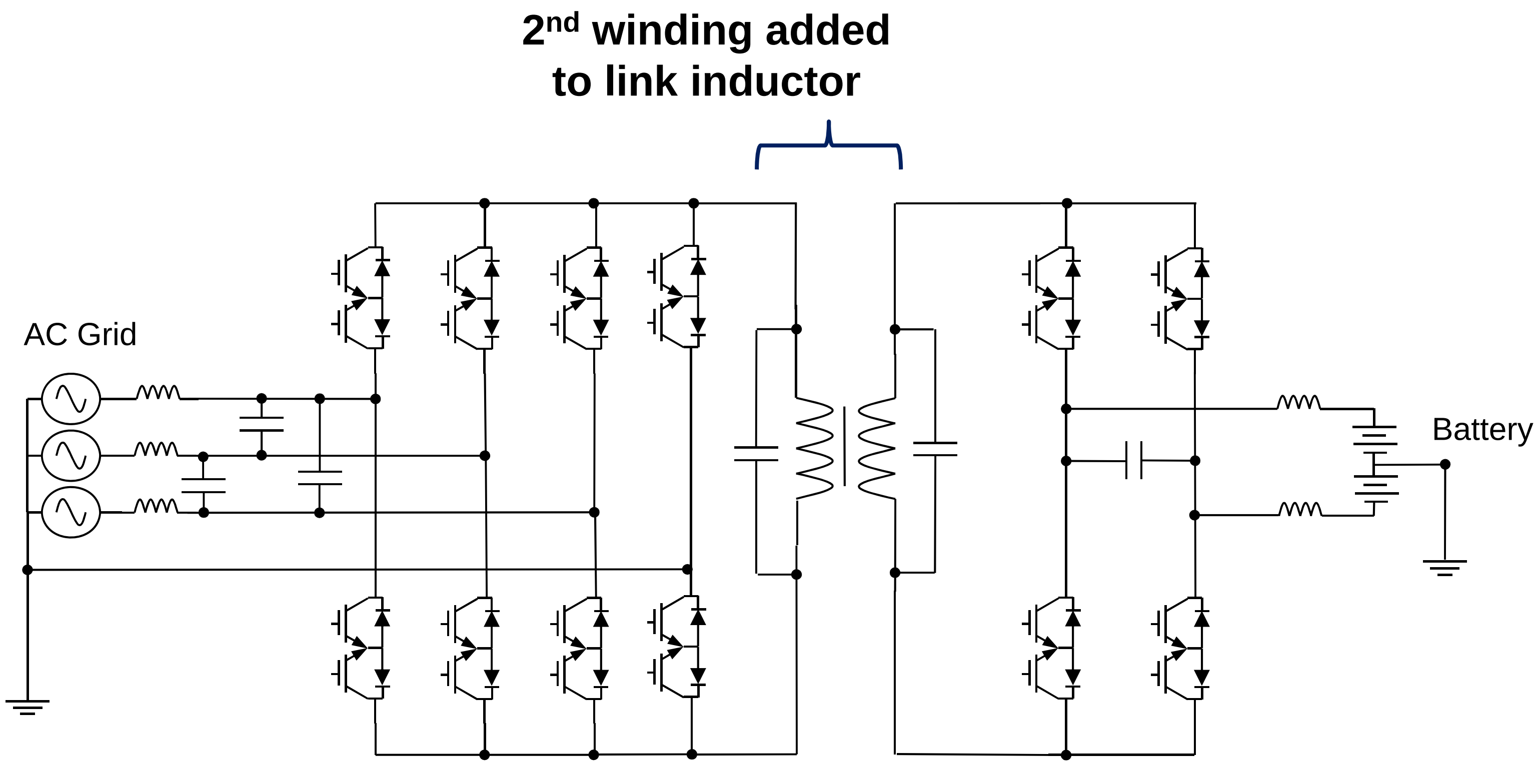
Bidirectional Battery Inverter with Microgrid

<u>4-wire 3-phase grid interface</u>

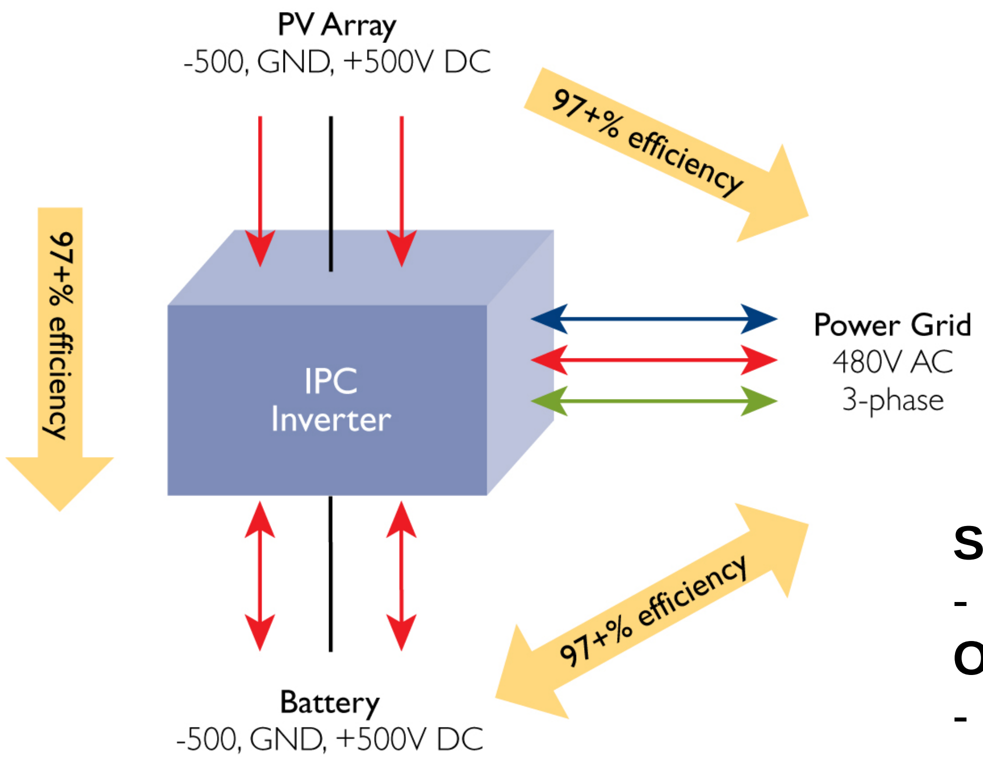
- Support Micro-grid – Intentional Islanding
- Support unbalanced loads & phase balancing
- Similar to 4-wire interface for HI Power
- Common Mode isolation



Bidirectional Battery Inverter with Galvanic Isolation



3-port PV & Battery Inverter



<u>4-wire 3-phase grid interface</u>
- Microgrid – Intentional Islanding
- Support unbalanced loads

Single-Stage Conversion
- Higher efficiency

Operates during faults
- Grid faults
- Communications faults

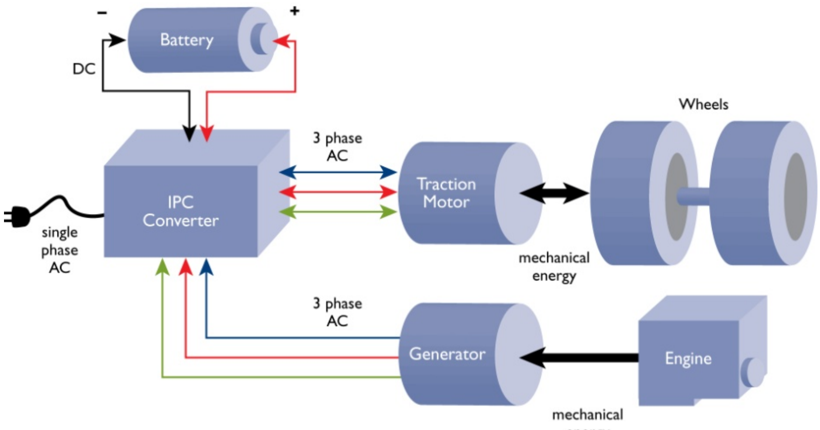
DC charging of EV during peaks
- Reduce peak load/transmission

<u>Station Battery</u>
- PV smoothing and peak shaving
- UPS capabilities

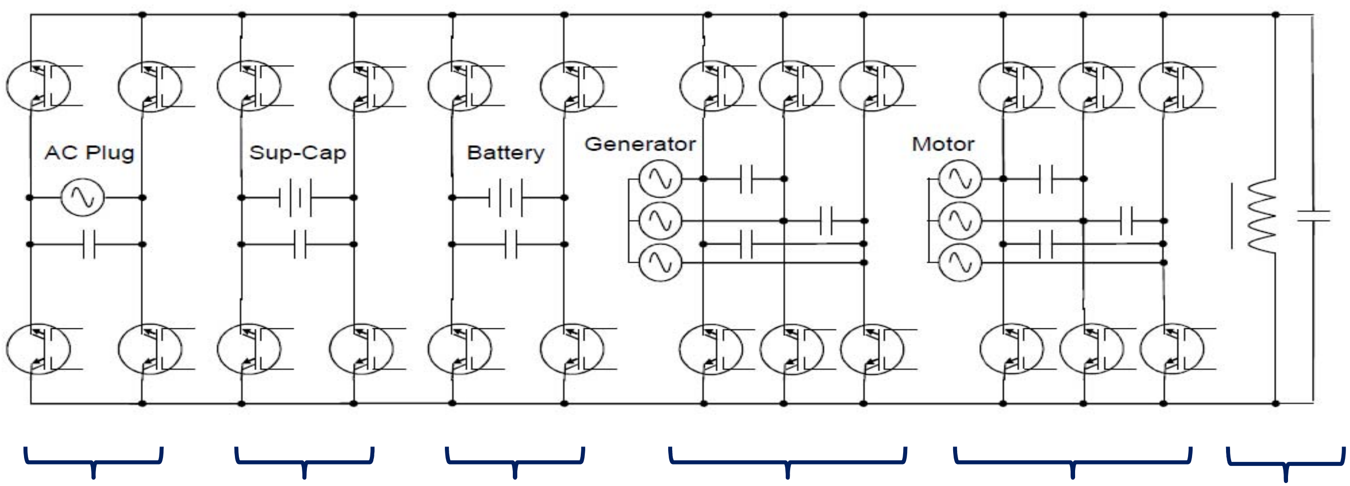
<u>Vehicle Battery</u>
- Bi-directional Level 3 DC charger

IDEAL POWER CONVERTERS

IPC PHEV Architecture



- Multi-port, multi-directional converter
- Superior efficiency, weight/size, cost
- Simplified cooling systems
- Supports inductor generator/motor
  - No PM or rare earths



120/240V single phase input charging	optional caps or 12V aux battery	high voltage Li-Ion battery	generator from internal combustion engine	drive motor with re-generative charging	link inductor

(note line capacitors not shown)

IDEAL POWER CONVERTERS

Backup Slides

IDEAL POWER CONVERTERS

Business Overview

- **Developed new electronic power converter technology**
  - 2 US patents issued, additional US and international patents pending
  - Applications: photovoltaic, wind, battery, VFD and PHEV
- **Licensed to Lockheed Martin for military & vehicle mkts**
  - Developing new microgrid converter for forward military bases

LOCKHEED MARTIN

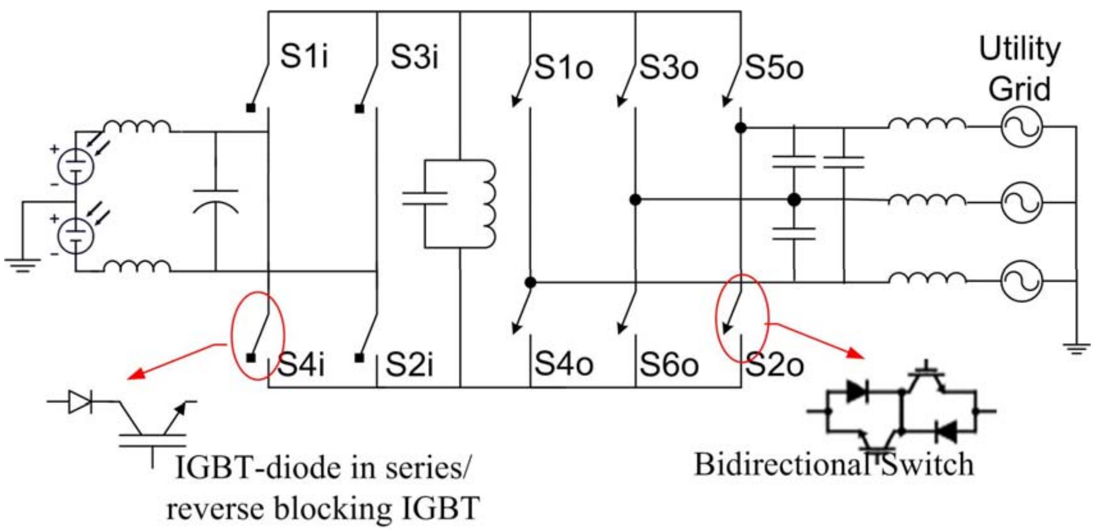
- **Received funding**
  - Texas Emerging Technology Fund
  - Battery Venture

BV

- **Initial product is 30kW PV inverter**
  - for US commercial-scale / flat rooftop installations
  - customers are commercial PV design & installation firms

IPC Topology Characteristics

- Soft-switched, buck-boost, current-modulated converter
- All power transfer is through a link inductor (not resonant link)
- Link operates at 7 kHz at full power, AC current/voltage
- Precise current control reduces output harmonics
- Link capacitor acts as loss-less snubber for ZVS
- Zero voltage turn-on, low di/dt reverse recovery
- Inherent isolation between input and output, no transformer needed



Military Funded R&D

- **Development contracts from Lockheed Martin**
  - Funded by DOD and LMC internal R&D budgets
  - Developing Intelligent Microgrid Solution under DOD/LMC contract

    "Reduces diesel fuel requirements up to 40% by improving microgrid efficiency for Forward Operating Bases" -Lockheed Martin

- **Technology License to Lockheed Martin**
  - Exclusive rights to military & automotive (specific) markets
    - IPC retains rights to sell commercial-of-the-shelf to military
  - Generates royalty from LM sales and sub-licensee sales
    - Minimum royalties escalates annually
  - Validates & strengthens IPC patents
    - IPC retains all IP ownership
    - Royalty free rights to LMC improvements

3) PCS Architectures for PEV as Storage

Session 3.3

Casey

Large Grid-Supportive Inverters for Solar, Storage, and V2G

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

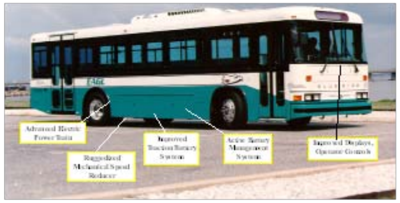
Leo Casey

6/13/2011

Satcon

Our Alternative Energy Journey



1985 MIT-DRAPER

Patriot - 1992

BEACON 1997

Magmotor 1997

FMI & HiComp 1998

WEC/NG 1999

InverPower 2001

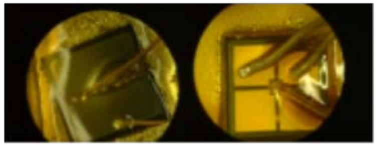
2003 Subsidiary Corporations

Divested 2007

RCT Systems 2009

Today

- Grid Products
- #1 Utility Scale PV
- 400+ employees
- 2GW inverters



Energy Storage

Renewable Energy

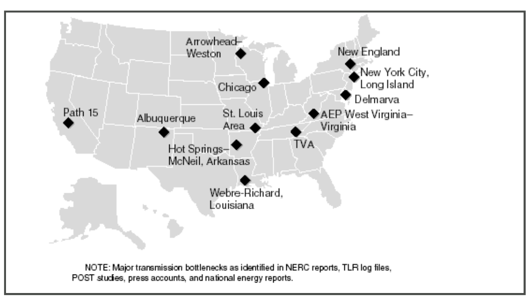
Distributed Energy

Grid Support

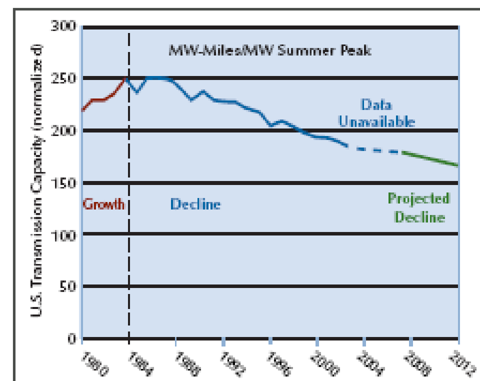
Technology Development

Electric Power – More Electric Future

- Dominant secondary source of energy
- Grid is a BEAUTIFUL thing
  - Instantaneous energy
  - ac
  - Rugged generators
  - Spinning “reserve”
  - Excess capacity (>15% is critical) **SIZED FOR 20%+**
  - Low Impedance
  - Fault clearance
  - Overload
- Beautiful, but
  - no significant energy storage
  - Supply must equal demand
  - generator power angle
  - minimal local control
  - Time constraints of protective devices
- Importance of storage (some storage)
  - Distribution (remoteness of generation and utilization)
  - Load leveling (excess capacity), energy arbitrage
  - Power Quality (4-5 9’s vs 5-6+ in EU)
  - Intermittent Renewables (**WIND**)



Electricity Infrastructure	
Transmission SCADA control points	
FERC grid monitor/control	12
Network Reliability Coordinating Centers	20
Regional Transmission Control Centers	130
Utility control centers	>300
Power plants	10,500
Large (>500 MW)	500
Small (<500 MW)	10,000
Transmission Lines	680,000 miles
Transmission substations	7,000
Local distribution lines	2.5 million miles
Local distribution substations	100,000



U.S. Transmission Capacity Normalized by Summer Peak Demand.

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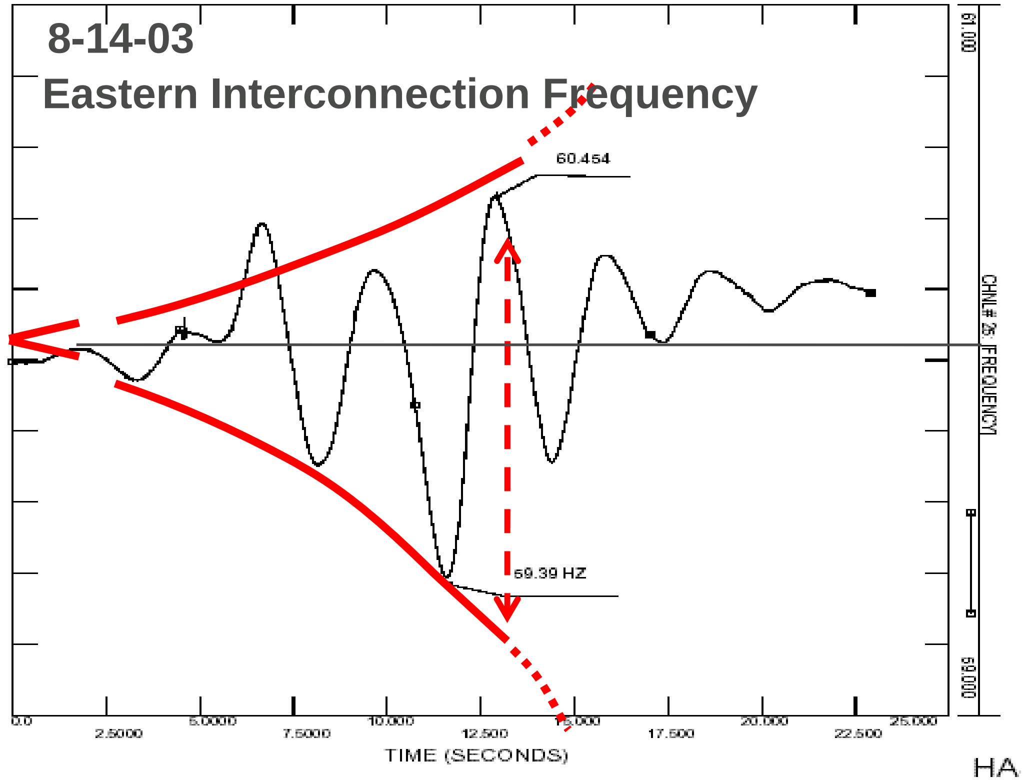
Modern Grid Issues

- An age of Increasing Electrification (~1TW capacity in EI),
  - BUT
    - Energy sources problematic (climate, security!)
    - Grid Power Quality is inadequate to electronic age (many aspects to this)
    - Slow and Archaic Electromechanical Hardware & Controls
    - Congestion in T&D infrastructure
    - NIMBY etc
  - SOME ANSWERS
    - Demand Response (time scale?)
    - Efficiencies
    - Renewables
    - Hi-Speed Controls
    - Hi-Speed Devices
    - Reconfiguration
    - DC transmission
  - TO SOME PROBLEMS



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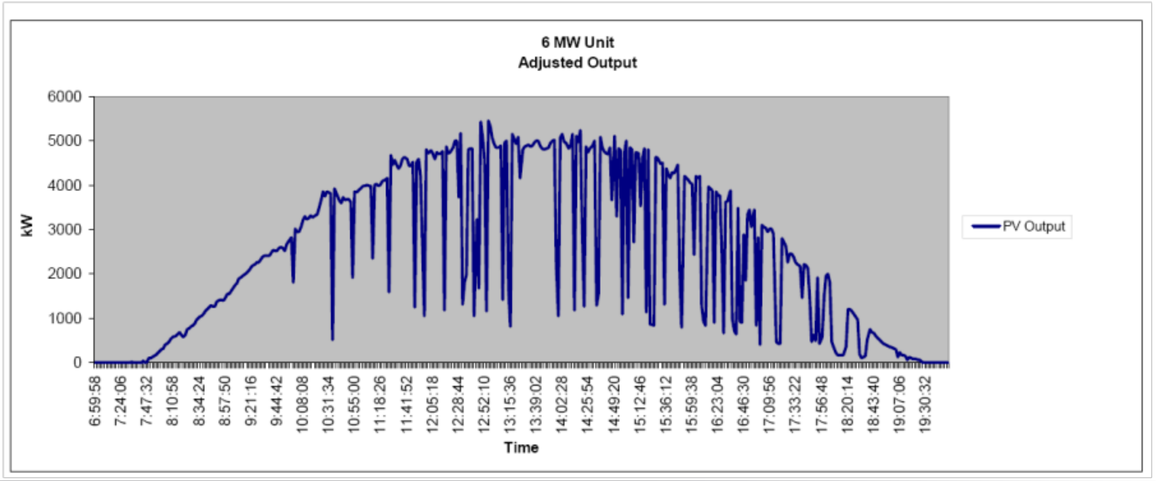
Renewable Energy and EV Challenges

- Renewables Intermittency
  - Large, sudden changes in plant output power can result in power quality degradation (e.g., flicker)
  - Existing grid infrastructure has much slower reaction times than renewable intermittencies
- Electric Vehicle Charging
  - EV charging, especially during peak periods, stresses utility infrastructure
  - New charging infrastructure is required for ubiquitous charging capability

PV Plant Power Output Fluctuations Due to Passing Cloud Cover



Background: Capabilities of Existing Inverters (Converters)

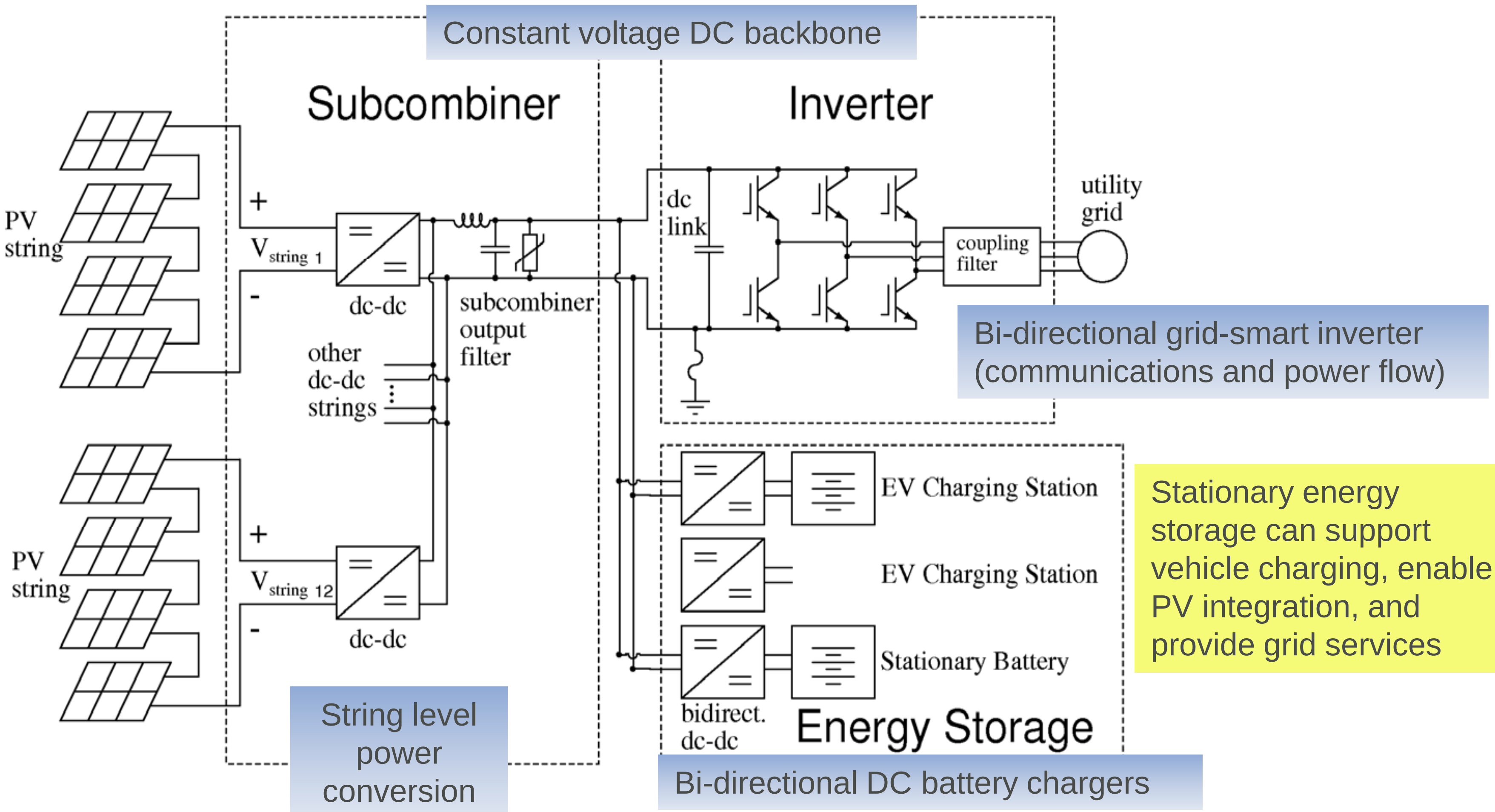
- **Bi-Directional Real and Reactive Power Flow:** Capable of absorbing or delivering real and reactive power
  - Voltage regulation, fully adjustable power factor – potential to provide autonomous or utility-directed control
  - Curtailment commands used to control ramp rates
- **Site-level control:** Provides aggregated power management functions at PCC with the utility
  - Can manage multiple inverters and/or energy storage
- **Communications with the utility (SCADA, PLCC):** has been used to demonstrate utility-directed real power limits, ramp rate, and reactive power control
- **Ride through capability for specified disturbances**
- **Two stage architectures facilitating energy storage**
- **Ac/dc microgrids**

Satcon

Vehicle Charging Energy Storage Design Tradeoffs

- **Concentrated/Centralized vs. Distributed Architectures**
- **Energy storage:** Mobile storage only vs. stationary + mobile storage
  - Maintaining localized power quality, aggregating/managing energy storage, and meeting demand using only mobile resources presents a formidable challenge at high penetration. Limited by existing infrastructure.
  - Stationary storage could act a buffer to mitigate these issues, and provide rapid charge capability
  - Real world experience is needed to assess appropriate blend of stationary and mobile energy storage resources.
- **Integration with PV:** Significant advantages compared to standalone energy storage architectures
  - Leverages existing grid connection hardware (*low cost*)
  - Enables tightly-coupled synergistic interaction between PV and energy storage (*enhances functionality of PV and energy storage*)
- **Microgrid:** PV + battery can provide the basis for a high reliability microgrid

Two-Stage Architecture Integrated with Energy Storage



Stationary energy storage can support vehicle charging, enable PV integration, and provide grid services

Simultaneously enhances the value proposition for E.V.s and PV

Enhanced Inverter Capabilities Enabled by Energy Storage

- **Improved capacity factor**: Small amounts of stored energy can mitigate intermittency of renewables
  - Rapid changes in the real power output of renewables affect power quality (voltage and frequency), frequently necessitating curtailed operation
  - Stationary batteries act as a buffer to absorb rapid variations in plant output power enabling controlled ramping and reducing or eliminating the need for curtailment
  - Simulations by Satcon indicate that a narrow (+/-5%) state of charge window eliminates the need for curtailment (20 kW PV, 10 kWh battery)
- **Grid Stabilization:** Sub-cycle real and reactive power control
- **Reliability:** Enables extended ride through and provides voltage and frequency support for both plant AND grid induced disturbances
- **Flexible Load Management (i.e., peak shaving):** EV charging loads can be shed by the Utility or PV plant so the full PV power output can be used to meet peak demand spikes
- **Simplified Integration:** Capacity factor and reliability enhancements can be implemented on a *fully localized basis*, without the need for utility communications or control; inverter's PCC and site controller provide a natural gateway for managing V2G services

Enhanced EV/Stationary Battery Value Proposition

- **Efficient recharge:** Charging directly from DC bus eliminates round trip AC to DC energy losses, and chargers are upwards of 98% efficient
- **Level 3 DC Charging:** Charge rate is limited primarily by battery C-rate, not charging infrastructure
- **Low-cost:** Modular bi-directional DC-DC converters can be manufactured and installed at low incremental cost compared to dedicated Level 3 EV charging stations
- **Simplified control/aggregation:** Tight integration of stationary batteries with PV enables fully localized control of charging and provides a single site controller for communications with the utility
- **Renewable:** All PV charging is 100% renewable solar power (not just “certified green power”, but actual “renewable electrons”)

Satcon's Integrated Energy Storage Demonstration Activities

- PICHTR[1] funded demonstration of Grid-Interactive DC Link PV Charging Station
  - Project Partners: CU-Boulder, Host site at Castle & Cooke resorts on Lanai
  - 15 kW PV, bi-directional Solstice Inverter, bi-directional DC-DC converter, and Plug-In Prius (10 kWh battery)
  - Demonstrates rapid recharge, ramp rate control, load balancing of PV, and power factor control
  - Expected completion in October 2011
- CEC[2] funded demonstration of Grid-interactive PV System with a DC-link Stationary Battery
  - Project Partners: SMUD, A123, RES, host site at planned SolarHighways site
  - 500 kW PV, bi-directional 500 kW Solstice inverter, 500 kW bi-directional DC-DC converter, 500 kWh stationary battery
  - Demonstrate load management, ramp rate control, voltage and frequency support, and bi-directional communications with the utility grid
  - Project expected to start August 2011
- DOE Santa Rita Jail Microgrid
  - Medium Voltage Static Transfer Switch
  - PV and Fuel Cell Inverters and Controls with CERTs

[1]Pacific International Center for High Technology Research
[2]California Energy Commission

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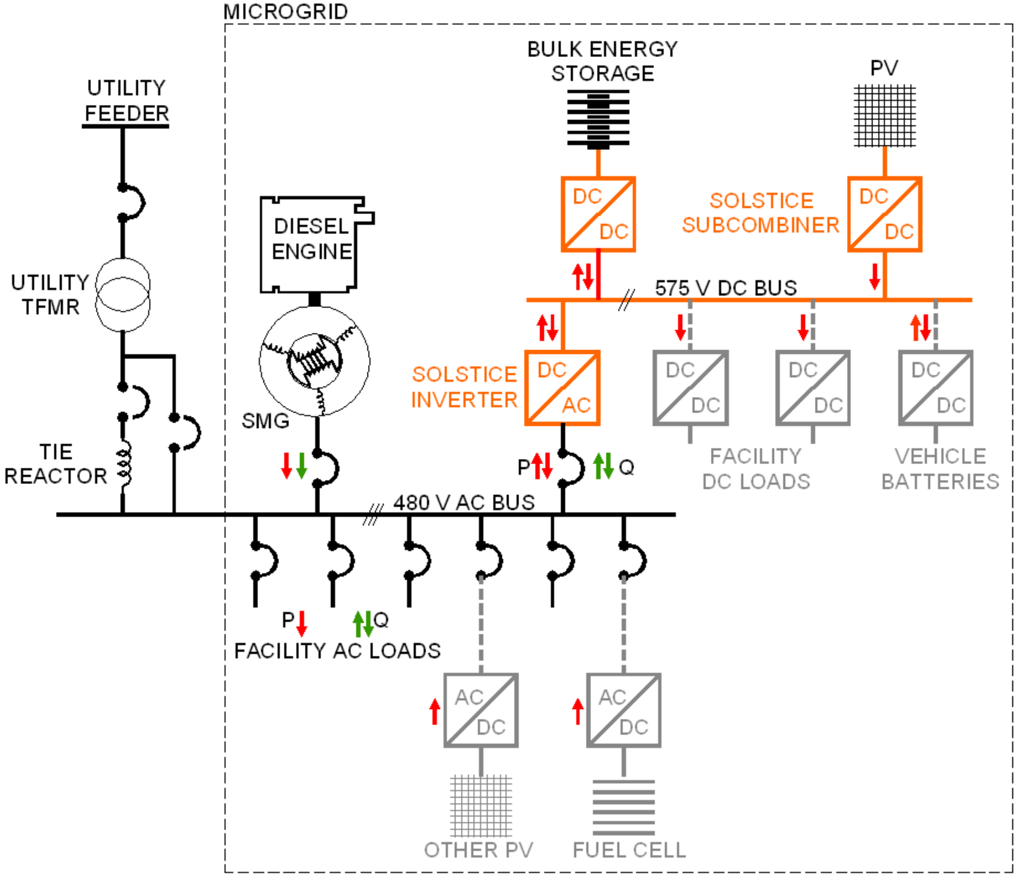
Hybrid Microgrid Utilizing Energy Storage

- Inverter maintains the instantaneous balance between generated real and reactive power and load ("swing generator") in a hybrid microgrid
- Solstice DC bus w/energy storage can power DC loads: e.g., EVs, DC data center, DC lighting
- High quality, nearly uninterruptible AC power during island conditions
- True uninterruptible DC power source during island condition



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Conclusion

- **Concentrated Inverters enjoy large cost advantages**
- Two-stage inverter architecture coupled with existing grid-smart inverter capabilities provide a natural platform for integration with stationary or mobile energy storage, mitigate problems and provide synergies
- **Benefits:**
  - **Improves PV capacity factor:** Narrow SOC excursions enables ramp rate control and effectively eliminate the need for curtailment
  - **Grid-side services:** enhanced reliability through real and reactive power delivery, extended ride through and voltage/frequency support; peak shaving
  - **Enhances the EV value proposition:** Low-cost, fully renewable level 3 recharge capability, low round trip losses,
  - **Simplified integration:** PV/EV synergies may be realized with localized, autonomous control (no utility involvement); inverter's point of common coupling and site controller provide a natural gateway for managing V2G services
  - **Microgrid:** Potential to realize a robust, high reliability AC/DC microgrid
- **Maturity:** Capabilities are currently being demonstrated

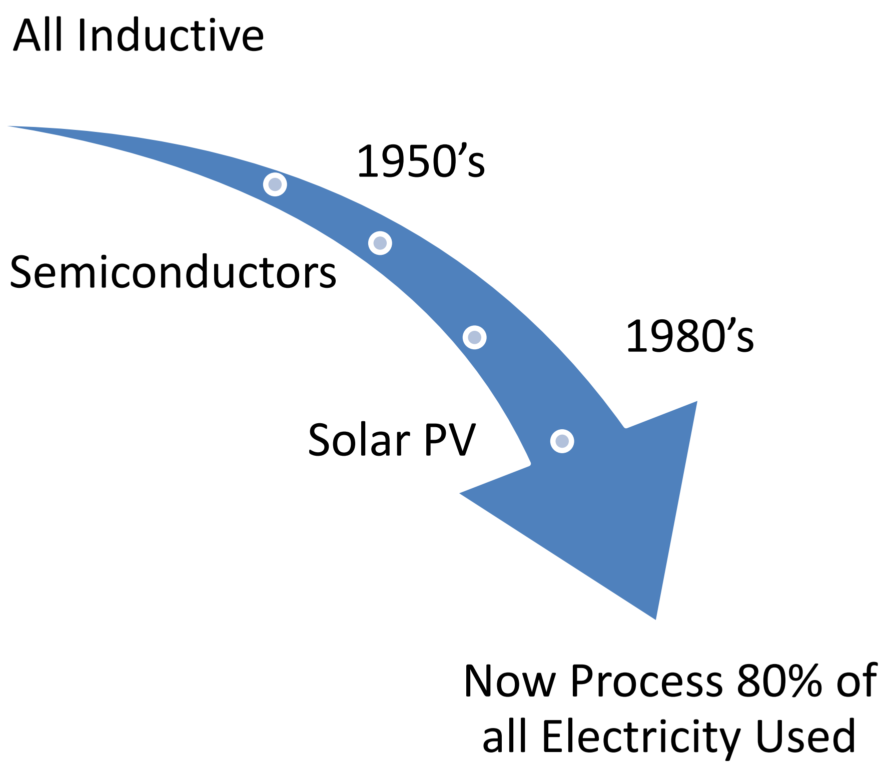
Satcon

Session 3.4
Savage

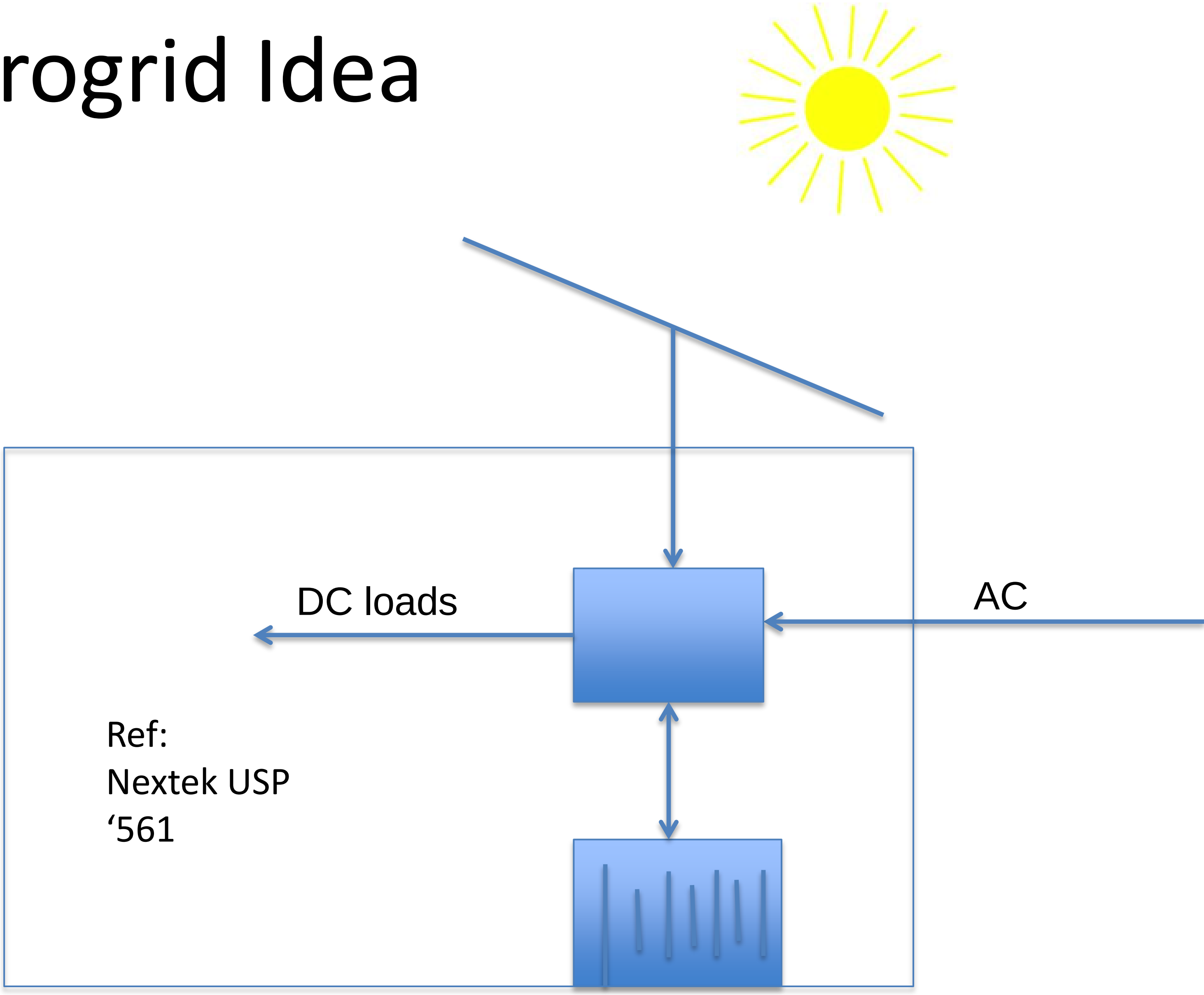
NEXTEK

Power Systems

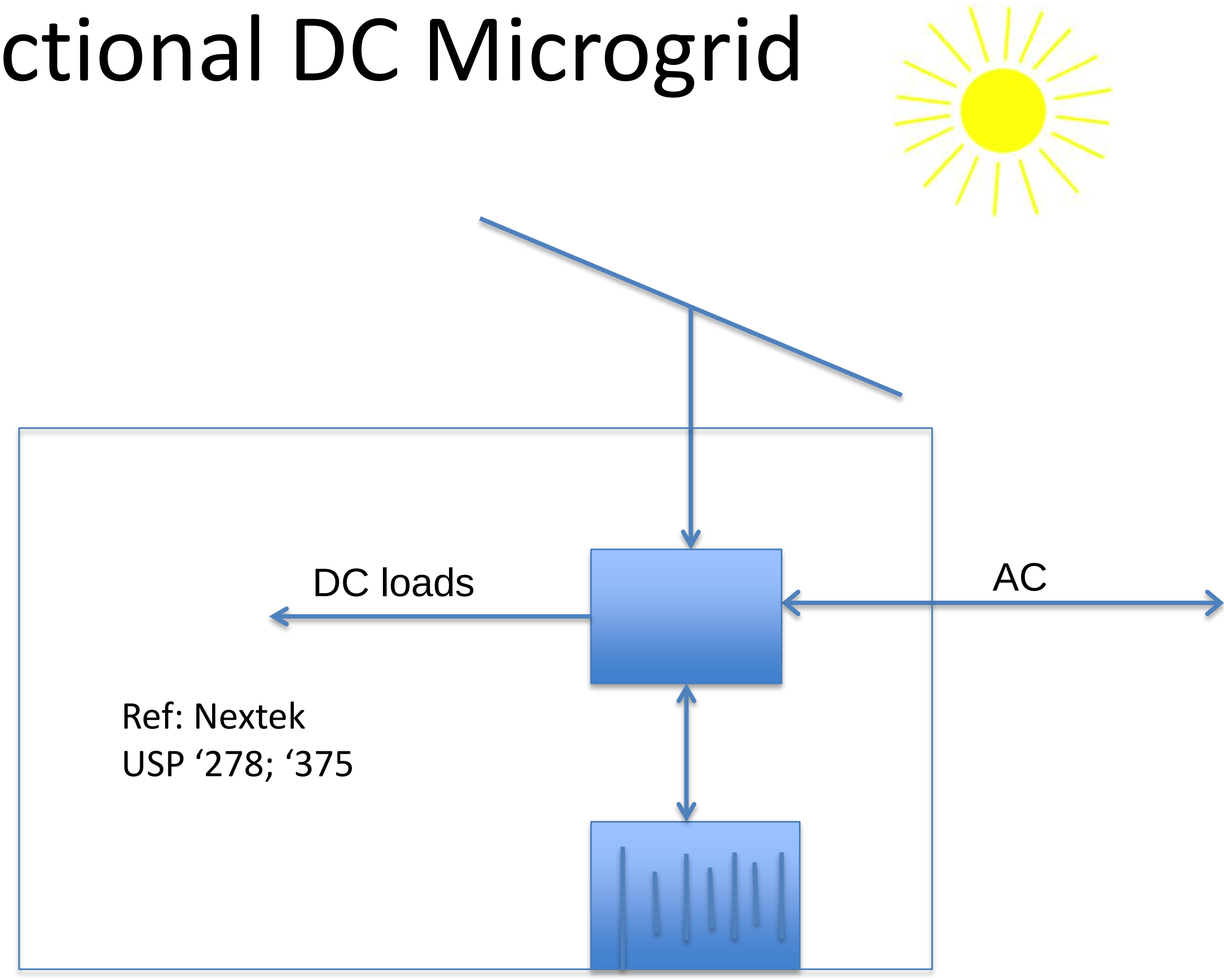
Shift to Semi-conductors



DC Microgrid Idea



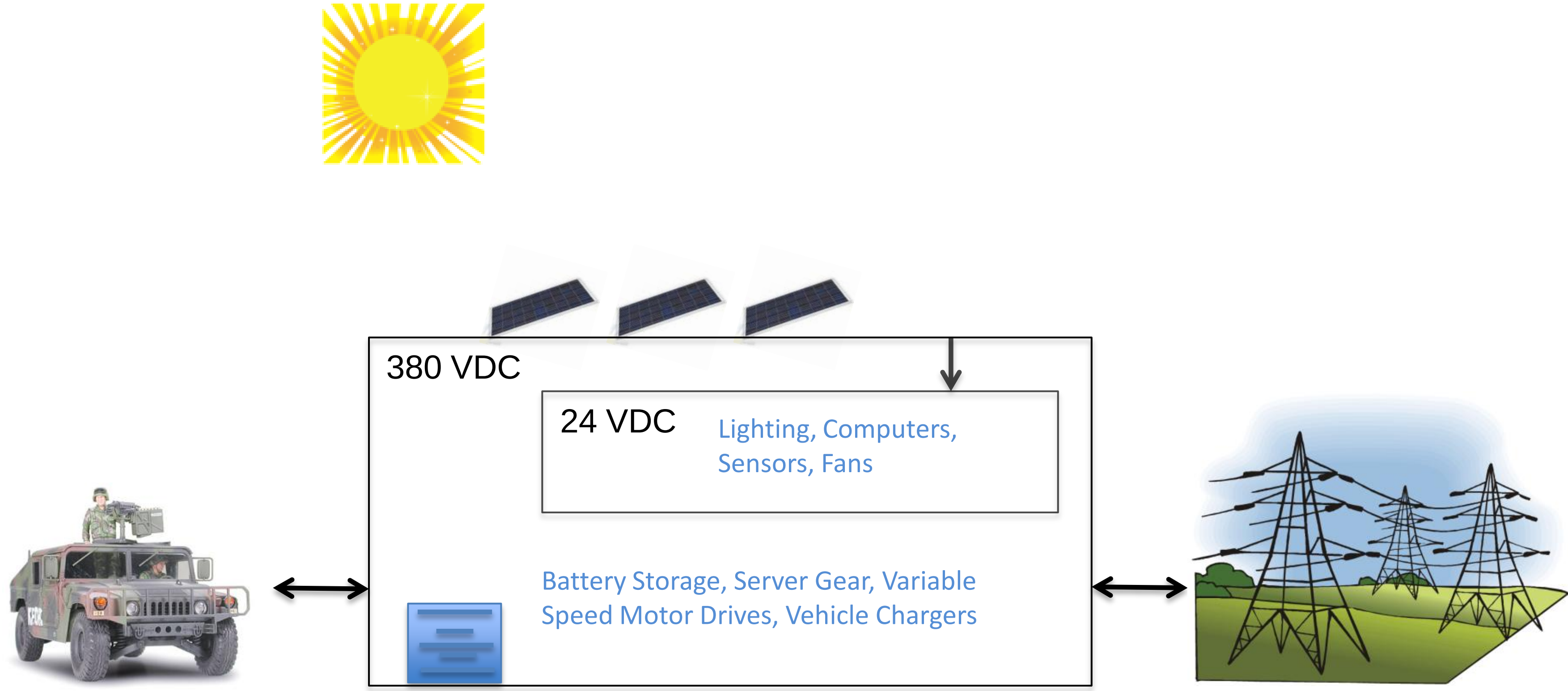
Bi-Directional DC Microgrid



“The total amount of energy flowing into external power supplies in the U.S. today is about 100 TWh/year. DC power is also used in electronic products with internal power supplies. These collectively consume in excess of 250 TWh/year. Taking the Energy Star Tier 1 levels as the average for the near-future stock, the average efficiency of this conversion is about 68%...”*

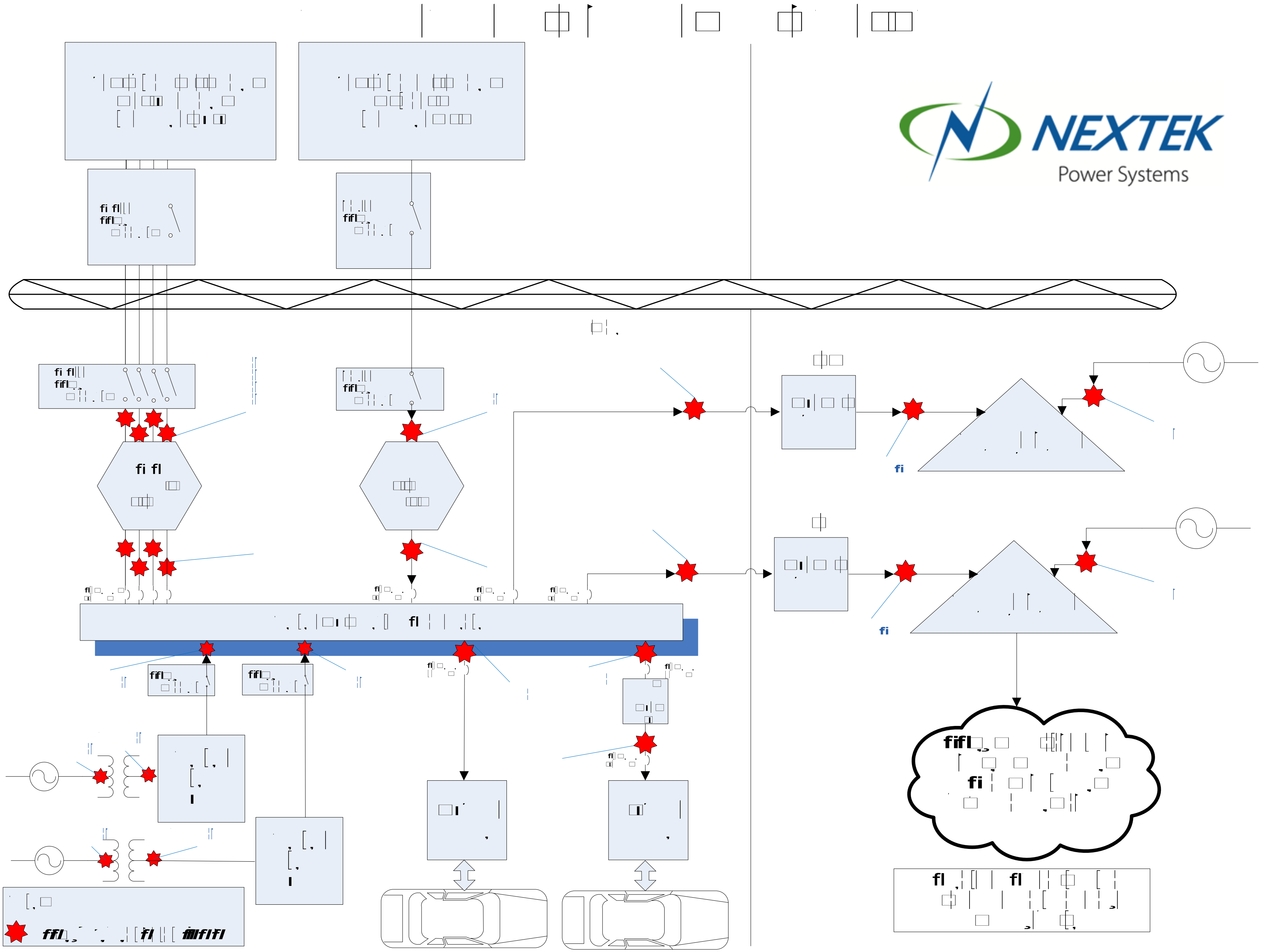
Sector	Potential MWh Saved	Potential Efficiency Gain in Sector(s)	Potential Reduction in National Load
Residential	185,264,820	25.32%	2.98%
Commercial	123,290,000	19.03%	3.03%
Manufacturing	77,128,960	20%	1.90%
Data Centers	9,657,827	18%	0.24%
Total	396,341,607	21.15%	8.15%

***Low-voltage DC: Prospects and Opportunities for Energy Efficiency** Bruce Nordman, Rich Brown, Chris Marnay Lawrence Berkeley National Laboratory, November 16, 2007



NEXTEK
Power Systems

Protected under US Patent# 7872375


NEXTEK
Power Systems

Michigan Assembly Plant

Birth Announcement

Welcome!

- *24 VDC*
- *380 VDC*

XOXO ~ 75 Stakeholders

Installations Around the Country

PNC Financial
Headquarters Office
Pittsburgh, PA

lauckgroup
Architectural Office
Dallas, TX

US Green Bldg Council
Conference Rooms
Washington, DC

Nextek Power NextEnergy
Center
Detroit, MI

UC San Diego
Sustainability Center
San Diego, CA










Southern Cal Edison
Utility Services Office
Irwindale, CA

Johnson Controls
Headquarters Office
Milwaukee, WI

Optima Engineering
MEP Firm
Charlotte, NC

LA Community College
Trade Tech Campus
Los Angeles, CA

CLTC
UC Davis Campus
Davis, CA

Session 3.4

Earley

Infrastructure Codes and Standards–the National Electrical Code®–Electric Vehicles and DC Power

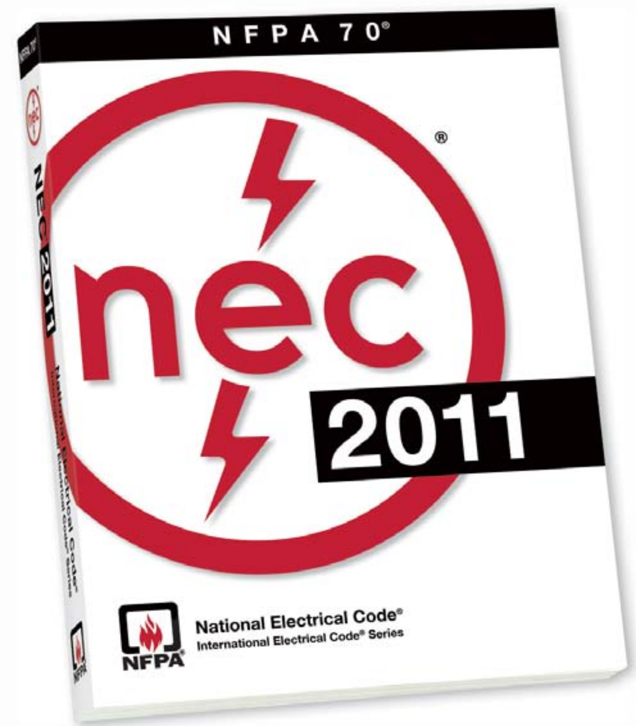
Mark W. Earley, P.E.
Chief Electrical Engineer
National Fire Protection Association

What is the National Electrical Code?

- Also known as the NEC ® or ANSI/NFPA 70
- There are two electrical codes that govern electrical installation
  - The National Electrical Safety Code®–governs electrical and communications utility installations
  - The National Electrical Code®–governs electrical installations in the built environment

History

- First edition issued in 1897
- There have been 52 editions
- Since 1953, the NEC has been issued every three years
- Adopted into law



National Electrical Code® Articles on Alternative Energy

- Alternative Energy Sources
  - Article 480–Batteries
  - Article 625–Electric Vehicle Charging Systems
  - Article 690–PV Systems
  - Article 692–Fuel Cells
  - Article 694–Small Wind Systems
  - Article 625–Electric Vehicles
  - Article 705–Interconnected Electrical Power Production Sources

Article 625–Electric Vehicles

- Section 625.26 recognizes interactive electric vehicle charging infrastructure.
  - Listed for the purpose
  - Used in optional standby systems (Article 702)
  - When used as a production source Article 705 also applies

Microgrids

- Who owns it?
  - Utility–National Electrical Safety Code®
    - 29 States do not allow other entities to sell power
  - Non Utility–National Electrical Code®
- Whose side of the line of demarcation is the equipment on?
  - National Electrical Code®
  - National Electrical Safety Code®

Article 705

- The pivotal article for alternative energy requirements
- Necessary for combining sources
  - Protects the premises
  - Protects the grid
  - Protects workers

NEC Requirements

- Most general requirements apply to all electrical systems, regardless of power source

The Three Legged Stool

- Electrical installation requirements--*NEC*®
- Product standards –UL, NEMA, etc
    - Product testing to standards
- Electrical inspection (ensures compliance with the installation rules of the *NEC*, along with any product installation requirements

DC Requirements

- Have been in every edition since the 1897 edition.
- There are specific AC and DC requirements
- Where not specified, requirements apply to AC and DC

Thoughts to Ponder

- Are the Common Requirements a Good Idea?
  - Based on current applications, yes!
    - Based on current technology, the requirements of the NEC have worked well.
  - Higher power DC may present new challenges
    - Overcurrent protection
    - GFCI protection
    - AFCI protection
    - Switching
    - Circuit protection
    - Arc flash evaluation
    - Circuit separation

NEC TCC Task Group on DC

- Chaired by John Kovacik, UL
- Members from various parts of the *NEC* community and from parts of the electronics industry
- May be soliciting additional members with DC expertise

Conclusions

- Major changes to our Electrical infrastructure are on the way.
- The NEC has been very responsive to change
- The NEC has requirements for interactive electrical systems
- Safety must not be compromised in our quest to become energy independent and green!

Thank you!

4) Transition to PEV Fleet as Storage

Session 4.1

Gruenewald

Bus Fleet Vehicle-to-Grid (V2G) Storage

NIST Workshop: PCS Architectures for PEV Fleets as Grid Storage

June 13, 2011

NSI
Strategy. Insight. Results.

School Bus Fleet Background

- The school bus market is supplied by an oligopoly consisting of three OEMs: Blue Bird, International, and Thomas
- The size of the fleet is 450K vehicles
- Manufacturing capacity is 35K to 40K vehicles per year; currently mid 20K due to local government fiscal issues
- The vehicle replacement cycle is 12 years
- Average daily usage for a school bus is approximately 60 miles
- DoD has a school bus fleet of 8K vehicles

Why are School Buses Good PEV V2G Candidates?

- Predictable usage pattern resulting in availability to the grid of >75%
- Buses are stored in one of three locations: a depot, a school, or a driver's home
- Average range (with 30 to 50 percent margin) can be achieved with a battery of between 100 KWh and 130 KWh
- 25 PEV V2G buses = 1MW
- 77 percent of school districts have at least 25 buses
- Grid operators and utilities have identified PEV V2G capable school buses as an ideal grid storage device for supplying frequency regulation services

PEV V2G School Buses: Other Considerations

- Good candidates for battery leasing programs and vehicle leases that monetize frequency regulation services
- Zero emission vehicles for non-attainment areas
- “Natural aggregation” – i.e., depot and school vehicle storage – makes school buses attractive pilot candidates for utilities
- Incentives already exist in California to buy-down the purchase price of a PEV V2G school bus to the price of a conventionally powered diesel bus
- Can serve as a mobile power source for natural disaster events
- Depots and school vehicle storage areas lend themselves to the use of solar power to generate electricity for the buses

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Strategy. Insight. Results.

4) Transition to PEV Fleet as Storage

Session 4.1
Bryan

A Utility's Energy Storage and Fleet's Mileage Service Provider

June 13, 2011

This presentation is for discussion purposes, only, and contains forward-looking statements which reflect management's current plans, estimates and beliefs as of the date of the presentation. Future results could differ materially from those presented depending on future events and developments. Any future business transaction with the recipient will be based solely on a to-be-negotiated definitive agreement, and not this presentation.

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Fleet Energy owns batteries in commercial vehicles.

- Revenue Stream 1: end user pays “by the mile”.

- Revenue Stream 2: local utility pays “by the hour” for the use of the batteries.

FEC's Management Team

- CEO of FEC, LG Chavez, Automotive Fleets and Business Management
  - Burt Automotive Network, growth of $526M to $2.1B over 13 years
    - Managed 1,600 employees at peak in 2008
    - $1.5 Billion in 2008 Commercial Fleet sales of over 75k units
    - Customers Include: Qwest Communications, Hertz Rent-a-Car, Enterprise Rent-a-Car, Xcel Energy, Comcast, etc
  - Director and Vice President of Biological R&D at American Home Products
  - University of Colorado - Boulder, BA in MCD Biology; University of Virginia, Ph.D. in Microbiology and Immunology

- CTO of FEC, John Bryan, Utility Engineering Project Management
  - Program Manager at Xcel Energy, Led and Implemented Industry Leading Utility R&D programs including:
    - 1 MW / 7.2 MWh Wind2Battery Program w/ 11.5 MW Wind Farm integration to MISO Markets
    - Vehicle to Grid Vehicle Electrification: 6 Ford Escape Retrofit with MISO Markets Integration
    - Outage Management System: Real Time Outage Management and Feeder Signal Data
    - SmartGridCity: Program Management and System Benefits
  - Program Manager for Qwest Communications
  - Quality Engineer for Textron Automotive (production manufacturing for Ford, General Motors, Toyota, etc)
  - University of Missouri, MBA - Finance; Vanderbilt University, BE - Mechanical Engineering

Motor Vehicle Production

Table 1-15: Annual U.S. Motor Vehicle Production and Factory (Wholesale) Sales (Thousands of units)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	10 Yr Avg
Production, total	**13,025**	**12,774**	**11,425**	**12,280**	**12,087**	**11,960**	**11,947**	**11,260**	**10,752**	**8,673**	**11,618**
Passenger cars	5,638	5,542	4,879	5,019	4,510	4,230	4,321	4,367	3,924	3,777	4,621
Commercial vehicles[a]	7,387	7,231	6,546	7,261	7,577	7,731	7,625	6,893	6,828	4,896	6,998
% of Total	57%	57%	57%	59%	63%	65%	64%	61%	64%	56%	60%

[a] Includes trucks under 10,000 pounds gross vehicle weight rating (GVWR), such as compact and conventional pickups, sport utility vehicles, minivans, and vans, and trucks and buses over 10,000 pounds GVWR.

NOTES

Factory sales can be greater than production total because of sales from previous year's inventory.

Ward's stopped collecting sales data for *Passenger cars* after 2001 because sales data are very close to production data.

Numbers may not add to totals due to rounding.

SOURCE

Ward's, *Motor Vehicle Facts & Figures,* U.S. Production and Factory Sales of Cars, Trucks and Buses (Southfield, MI: Annual Issues).

Year of Total US Vehicle Fleet	Number of Vehicles in US	Millions of Tons of CO2
2008	255,917,664	1,643.17
2001	235,331,381	1,619.27

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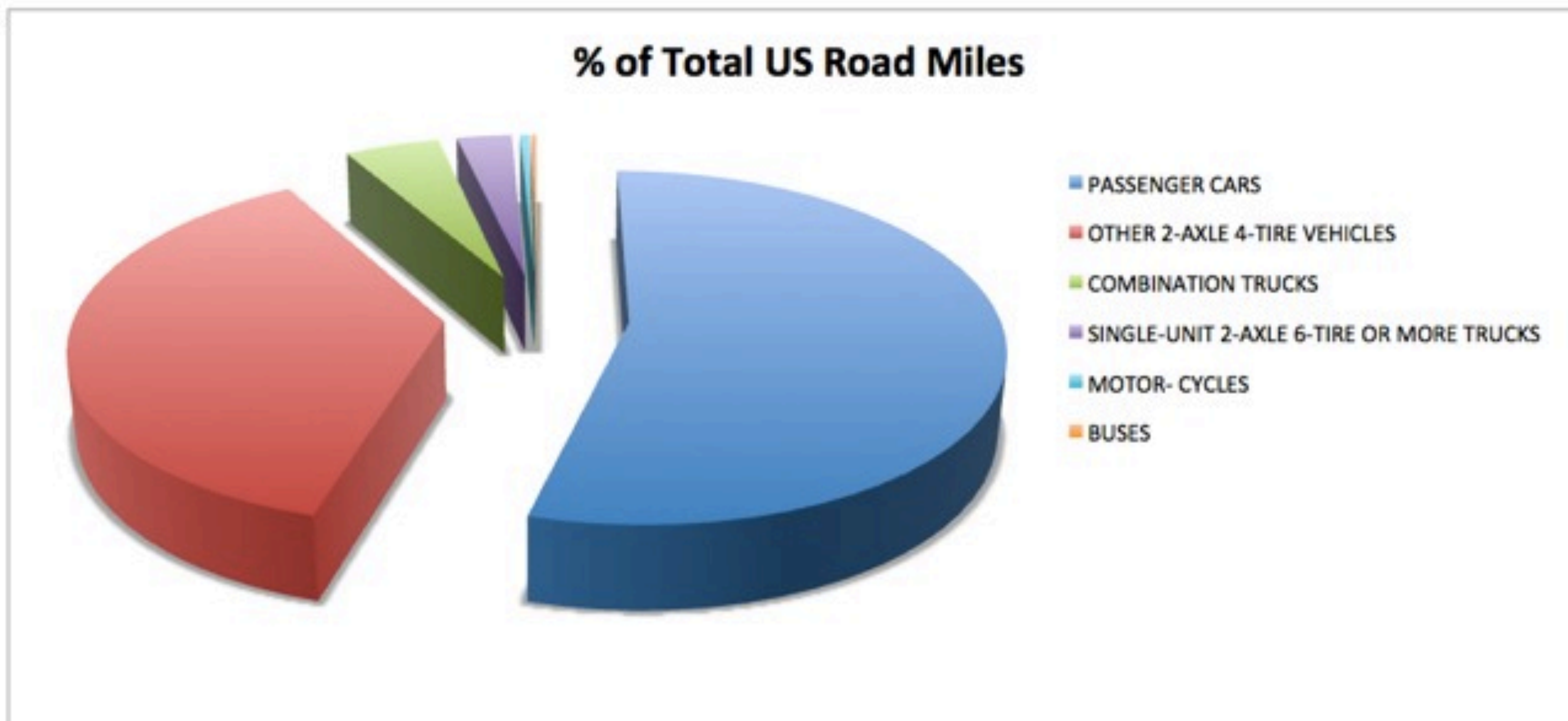
Vehicle Miles Travelled by Class

USA 2008 Data	PASSENGER CARS	MOTOR-CYCLES	BUSES	OTHER 2-AXLE 4-TIRE VEHICLES	SINGLE-UNIT 2-AXLE 6-TIRE OR MORE TRUCKS	COMBINATION TRUCKS	PASSENGER CARS AND OTHER 2-AXLE 4-TIRE VEHICLES	SINGLE-UNIT 2-AXLE 6-TIRE OR MORE AND COMBINATION TRUCKS	ALL MOTOR VEHICLES
Number of Motor Vehicles Registered	137,079,843	7,752,926	843,308	101,234,849	6,790,882	2,215,856	238,314,692	9,006,738	255,917,664
Millions of Annual Miles per Vehicle Class	1,615,850	14,484	7,114	1,108,603	83,951	143,507	2,724,453	227,458	2,973,509
% Miles in the United States	54.3%	0.5%	0.2%	37.3%	2.8%	4.8%	91.6%	7.6%	100.0%

Vehicle Type	% of Total US Road Miles
PASSENGER CARS	54.3%
OTHER 2-AXLE 4-TIRE VEHICLES	37.3%
COMBINATION TRUCKS	4.8%
SINGLE-UNIT 2-AXLE 6-TIRE OR MORE TRUCKS	2.8%
MOTOR- CYCLES	0.5%
BUSES	0.2%
kWh	4,119,000,000,000
MWh	4,119,000,000
GWh	4,119,000
Vehicles	6,238
	0.15%
	660.307791
hours of storage	13.26654042



50% of the US Fleet would hold 6,238 GWh of Electrical Energy Storage

US Electrical Grid Produced 4,119,000 GWh of Energy in 2009 (660 Times Bigger)

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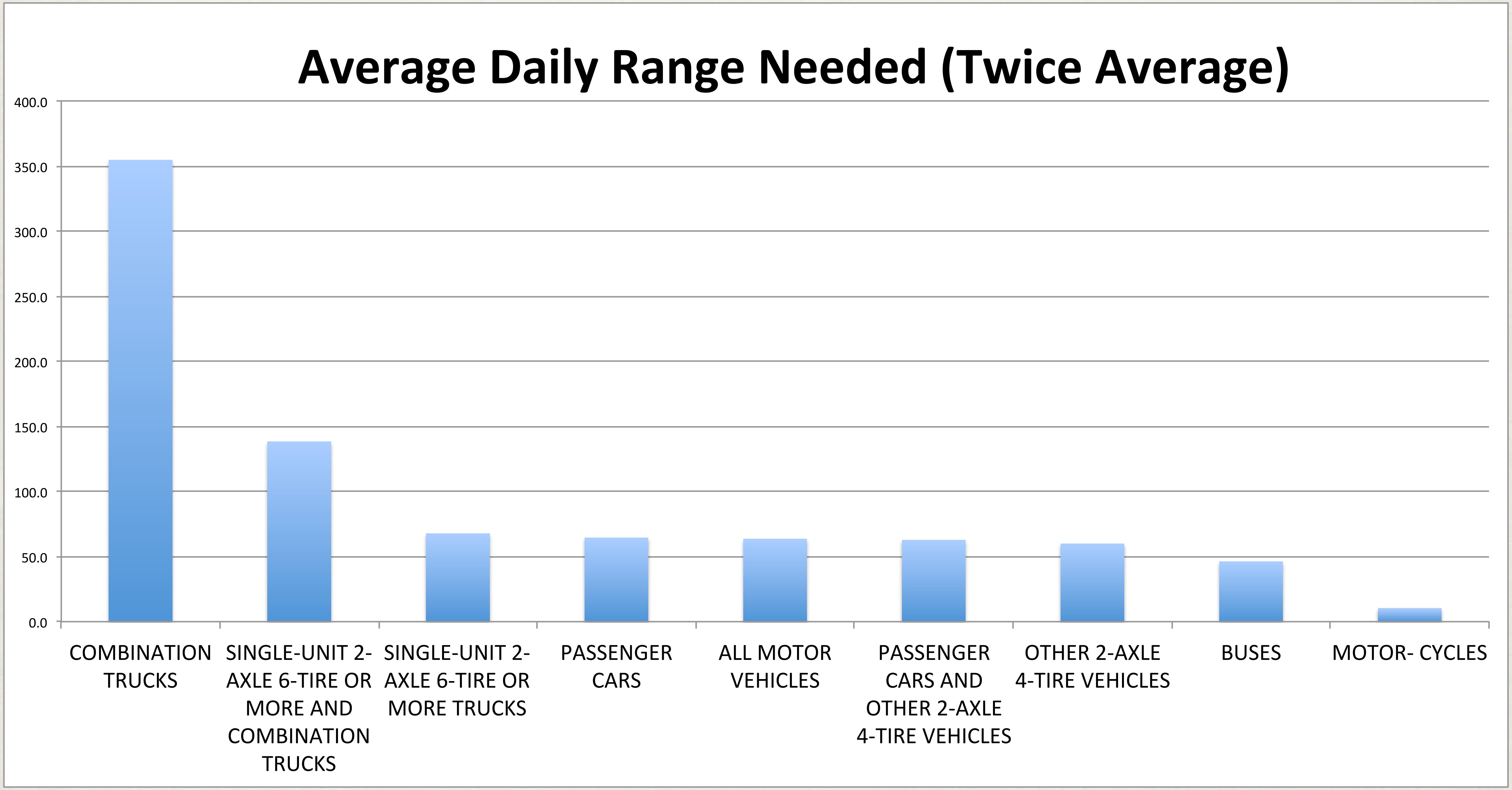
Double Average Range by Class



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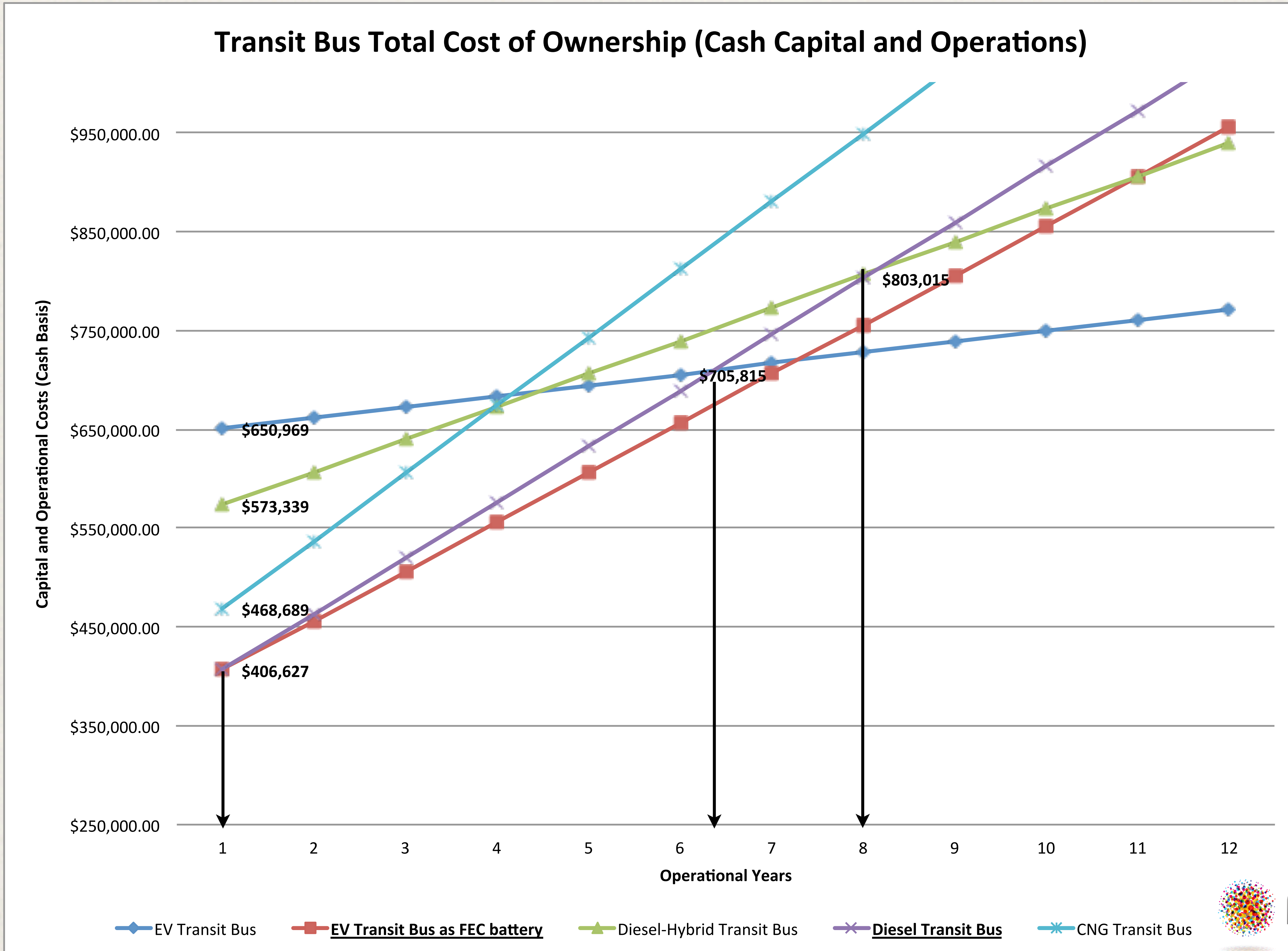
Top 100 Fleets or 1,007,906 Vehicles

- Grid Support is Marginal Utilization of Time
  - Per Mile of $96.35 per hour at $2.25 per Gallon
  - Per kW of $178 per hour at 2C Rate of (Dis)Charge
- Fleet Opportunities
  - Transit Buses
  - School Buses
  - Delivery Fleets
  - Insurance Companies
  - Utility Companies
  - Religious Organizations
  - Waste Management Organizations
  - Rail and Material Transport

Transit Bus Capital vs Operations



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Transit Bus Capital

Bus and Bus Facilities (5309, 5318): The Bus and Bus Related Equipment and Facilities and Bus Testing Facility

The Bus and Bus Related Equipment and Facilities program (Bus program) provides capital assistance for new and replacement buses, related equipment, and facilities. It is a discretionary program to supplement formula funding in both urbanized and rural areas.

Section 5318 is the Bus Testing Facility program. Under this program, one facility is used for testing a new bus model for maintainability, reliability, safety, performance (including braking performance), structural integrity, fuel economy, emissions, and noise. The program is administered under the Section 5309 Bus and Bus Related Equipment and Facilities program.

80% of Transit Bus Capital Cost comes from DoT-FTA

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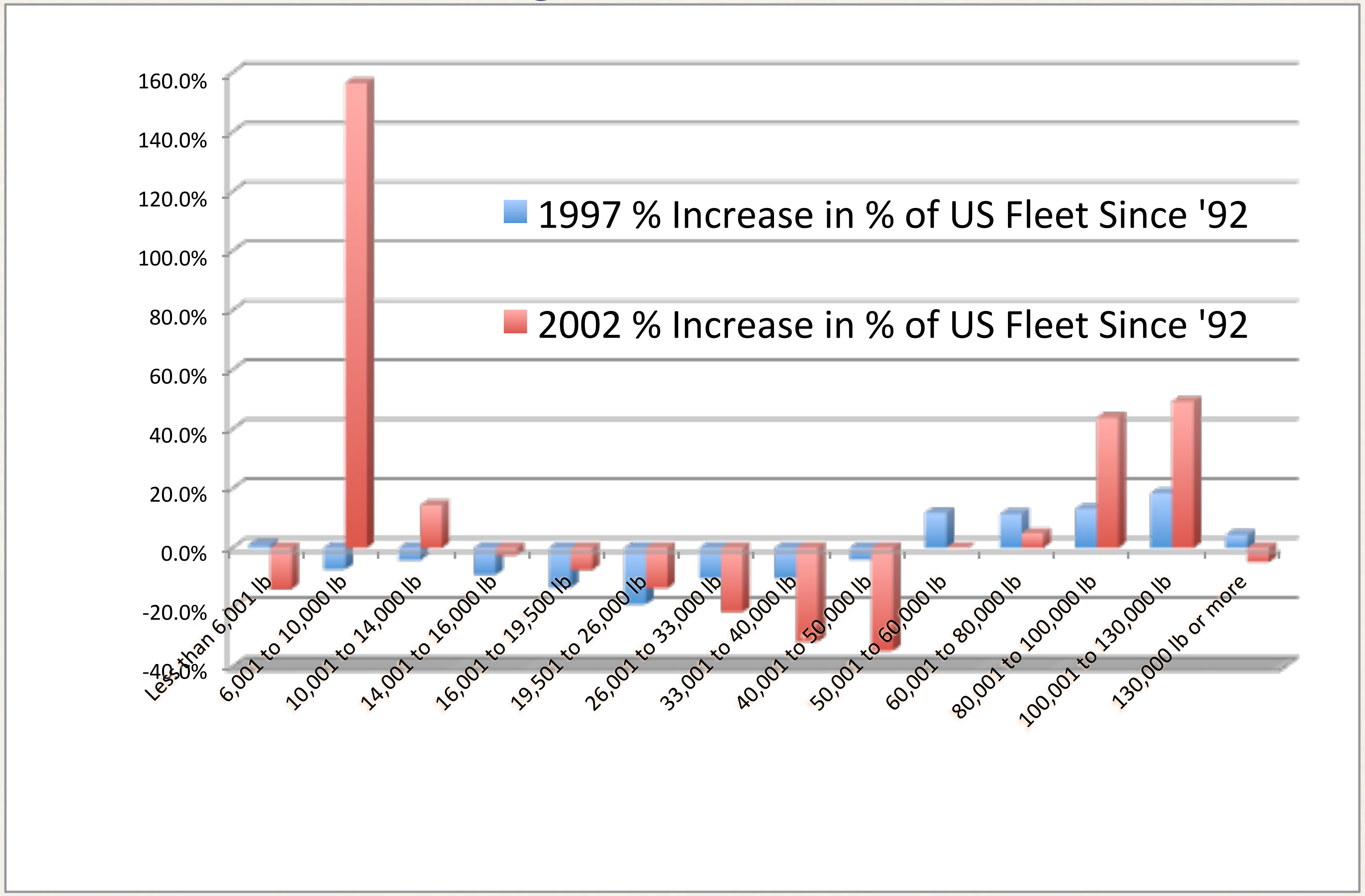
A School Bus...

- is parked at night, at peak, at mid day but has a defined route and is under fleet management.
- is parked at Tier 2 Emergency Crisis centers.
- emits harmful diesel emissions and contributes to global climate change.
- runs on imported fuel from unstable / unfriendly nations.
- is operated by schools in budgetary crisis.
- is one of 600,000 in the United States school system but is replaced on average every 20 years (the drive system tends to go first after 10 years).

An Electric School Bus...

- is parked when it can be always charged when it is needed but be filled with variable renewable energy to support the electric grid.
- would be a generation source in a regional / national crisis to maintain security in a disaster or as needed by schools or military bases.
- emits nothing while improving the integration of wind and solar on the nation's electrical grid.
- runs on local electricity which can not be outsourced while reducing greenhouse emissions by **273.98 tons of CO2 per bus**.
- will save $34,238 in school operational budgets per bus over its 20 year life.
- 600,000 Schools Buses fit the necessary range of an pure EV and save **16% of a GigaTon** of Carbon prior to considering improved renewable integration.

Class 3 Vehicles
(e.g. Ford F-350)



FedEx Express: "about 30% of our 78,000 vehicles could be 100 mile or less ranged electric vehicles"

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Top 100 Fleets

Brand	Chrysler	Ford	GM	Other	Total
Totals	115,103	245,543	229,717	33,474	623,837
%	18%	39%	37%	5%	100%

Class	Cars	Class 1-2 Truck	Class 3-8 Truck	Vans	SUVs	Cross-Overs	Total
Totals	208,009	263,756	227,037	212,652	43,774	10,683	965,911
%	22%	27%	24%	22%	5%	1%	100%

Operators of Top 100 Fleets

	Self	Wheels	PHH	GE Fleet	Lease Plan	Total
Totals	427,475	101,966	72,048	62,494	32,192	813,588
%	53%	13%	9%	8%	4%	82%

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Top 100 Fleet Vehicles

- Barriers
  - Utility Contracts Are Needed And Are Not Simple “Demand” Programs
  - Lack Of “Vehicle To Utility” Standard Communication Protocols
  - Financial Institutions Are “Wary” Of Utility Market Pricing
  - System Integration Is “Projects” And Not “Equipment Options”
  - Integrated Inverters (Discharge) Are Not Utility Scale (MW Not KW)
  - Public Utility Commissions Are Disjointed. Education Is Inconsistent
  - System Warranties Are Difficult To Describe
  - Federal Institutions Are Silos Not Systems (Transportation Vs Utility Budgets)
  - “Battery Moore’s Law” Creates A “Let’s Do This Later” Hesitancy

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Market Need #1

Electric Vehicle Batteries are Expensive

			High (and Low) Miles per kWh and Cost of Pack per Vehicle Class					
	High Cost of	Low Cost of	8	4	2	1	0.7	0.33
Range in Miles	Batteries (kWh)	Batteries (kWh)	Sub-Compact	Sedan	Small SUV	Class 3 Truck	Class 8 Truck	Transit Bus
40	$650	$350	$3,250 ($1,750)	$6,500 ($3,500)	$13,000 ($7,000)	$26,000 ($14,000)	$37,143 ($20,000)	$78,788 ($42,424)
75	$650	$350	$6,094 ($3,281)	$12,188 ($6,563)	$24,375 ($13,125)	$48,750 ($26,250)	$69,643 ($37,500)	$147,727 ($79,545)
100	$650	$350	$8,125 ($4,375)	$16,250 ($8,750)	$32,500 ($17,500)	$65,000 ($35,000)	$92,857 ($50,000)	$196,970 ($106,061)
150	$650	$350	$12,188 ($6,563)	$24,375 ($13,125)	$48,750 ($26,250)	$97,500 ($52,500)	$139,286 ($75,000)	$295,455 ($159,091)
200	$650	$350	$16,250 ($8,750)	$32,500 ($17,500)	$65,000 ($35,000)	$130,000 ($70,000)	$185,714 ($100,000)	$393,939 ($212,121)
400	$650	$350	$32,500 ($17,500)	$65,000 ($35,000)	$130,000 ($70,000)	$260,000 ($140,000)	$371,429 ($200,000)	$787,879 ($424,242)

A 100 Mile Range Electric Commercial Truck would cost $65,000...

...just for the battery.

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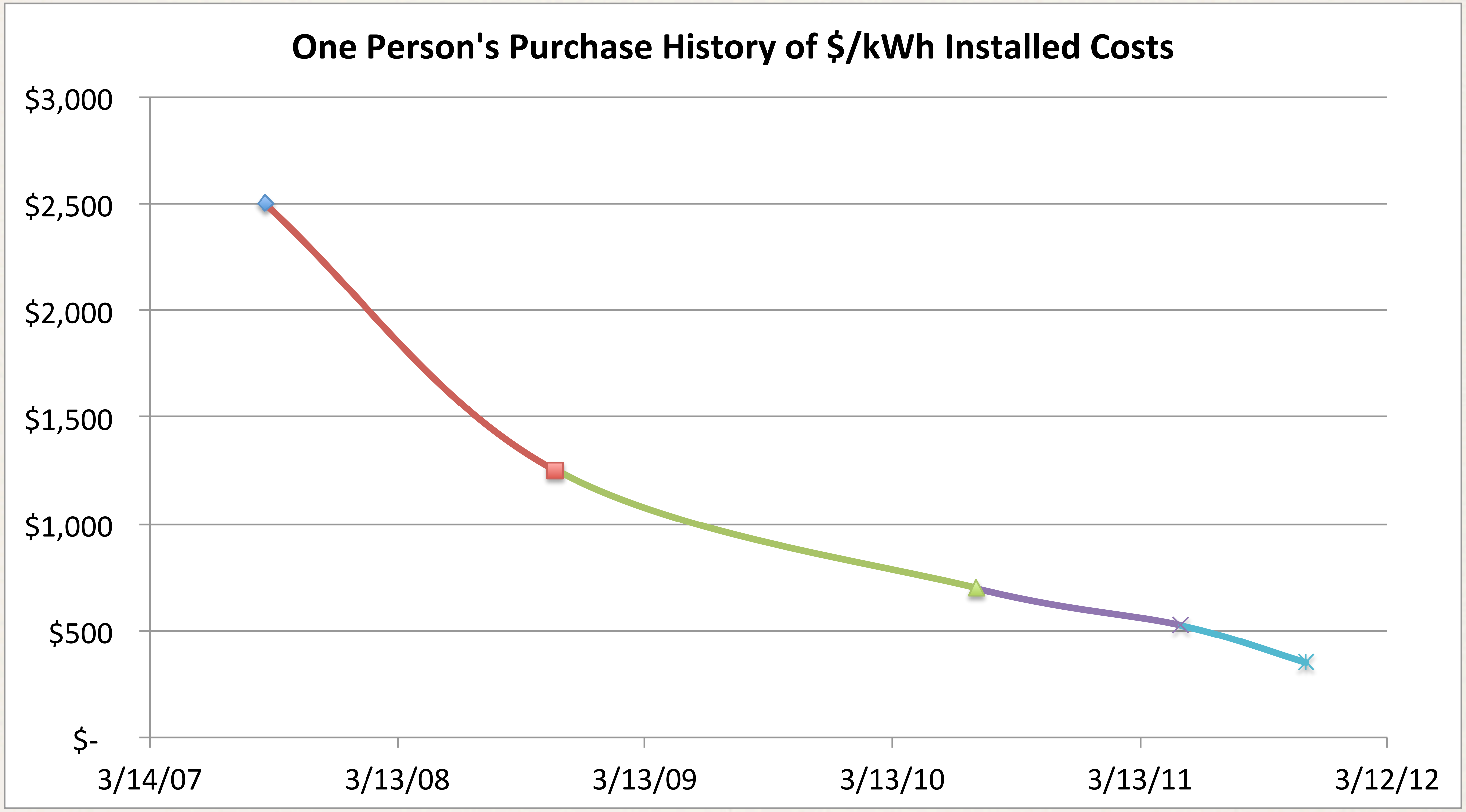
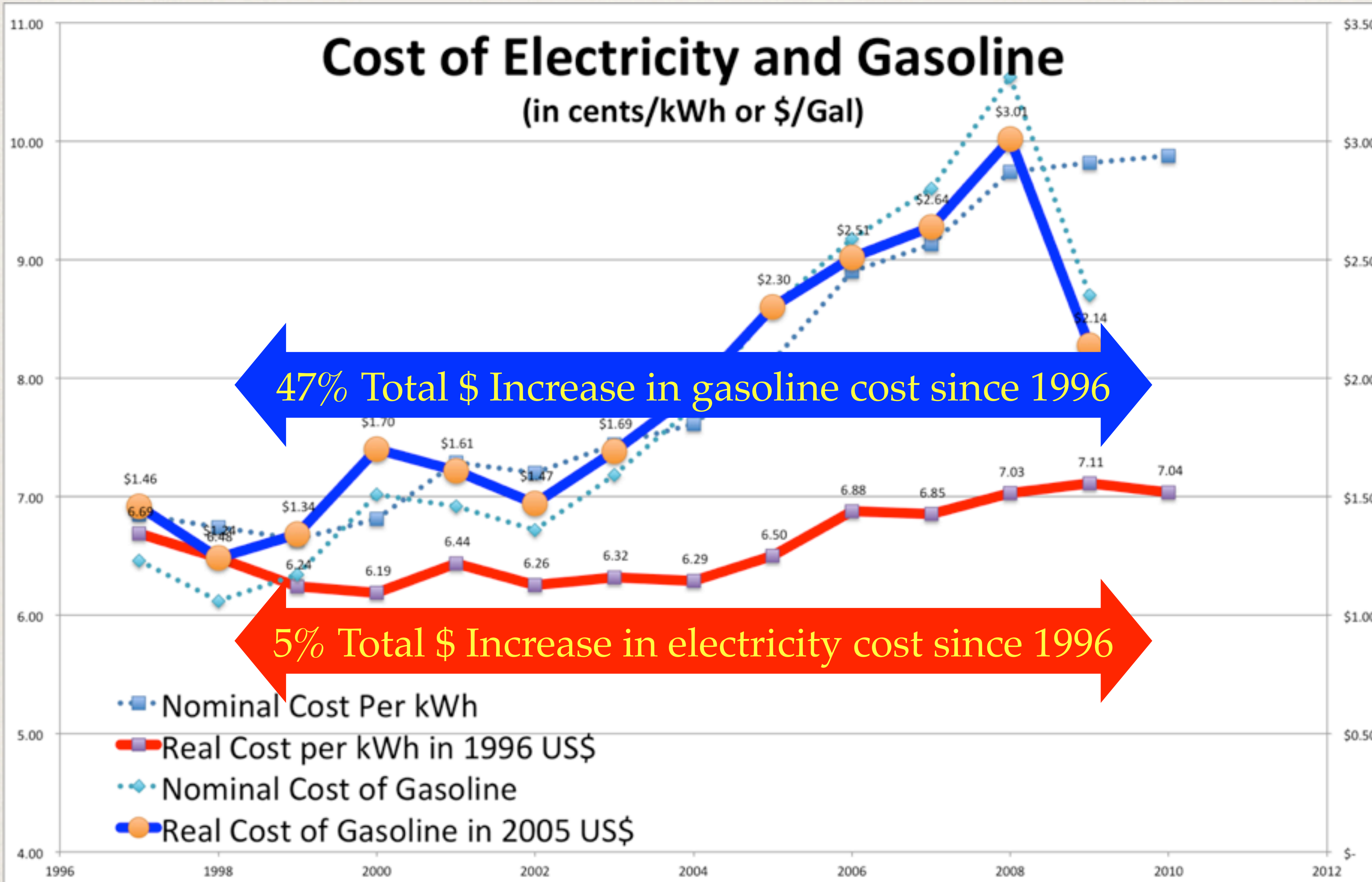
Fully Installed Li-ion Costs



Market Solution #1
Hedge Fuel Costs with Batteries

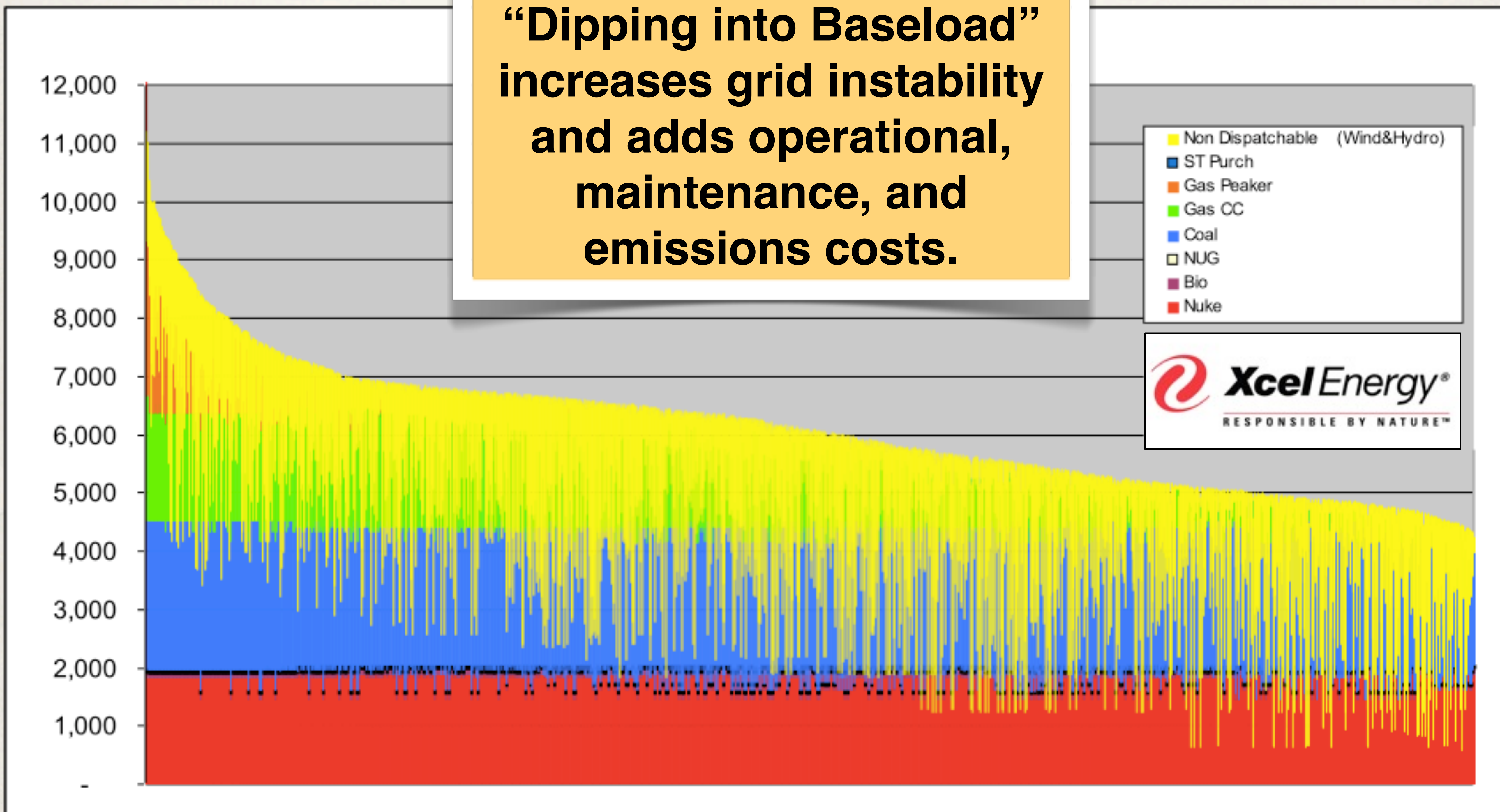


http://www.eia.doe.gov/emeu/aer/txt/ptb0524.html
http://www.eia.doe.gov/cneaf/electricity/epm/table5_3.html

Market Need #2

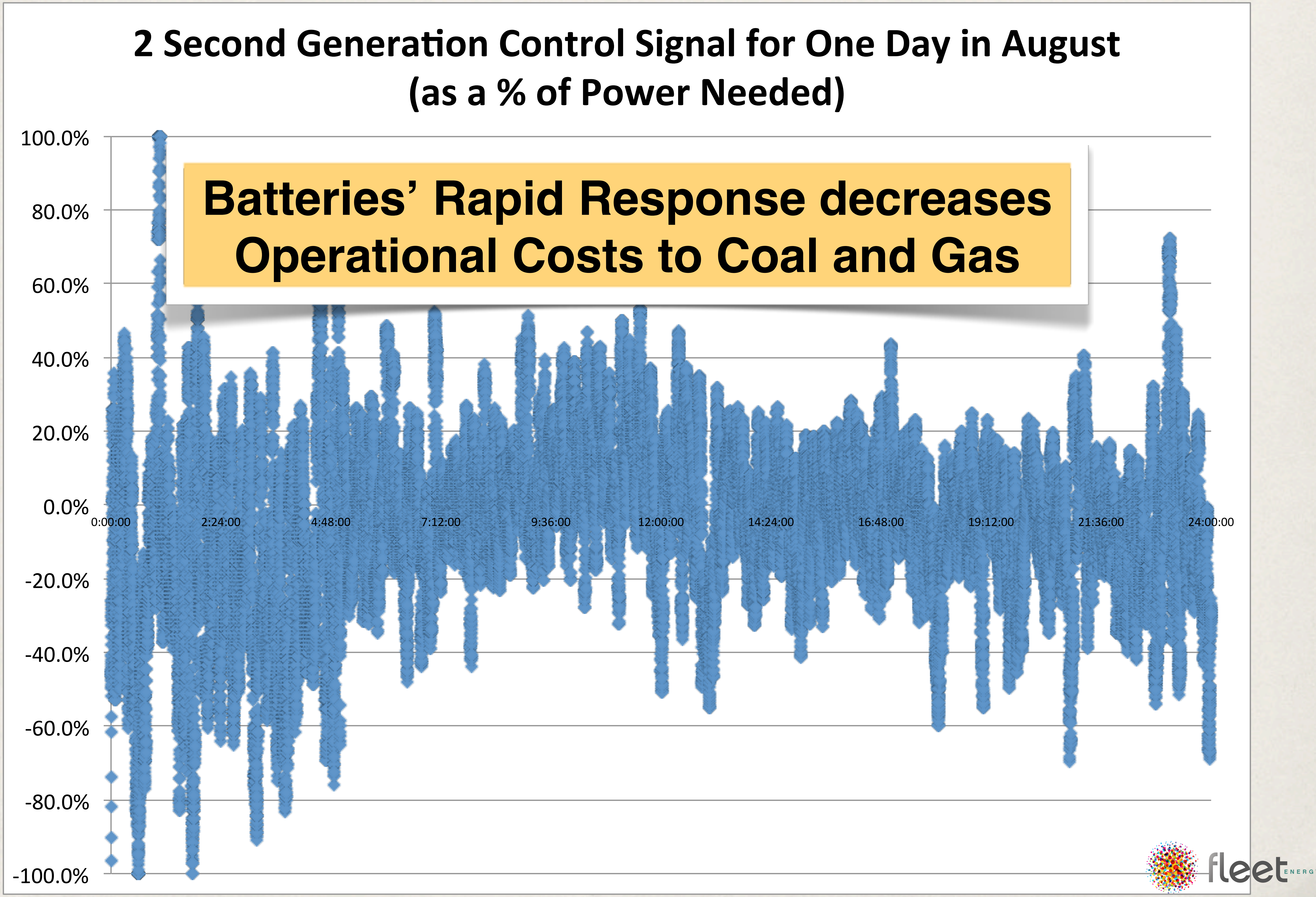
Wind (and Solar) is Problematic

“Dipping into Baseload” increases grid instability and adds operational, maintenance, and emissions costs.



NSPM System: Effect of Absorbing 30% of Wind Energy

Market Solution #2



Trucks by Weight

Table 1-21: Number of Trucks by Weight

	Thousands of trucks			Percent change 1992-1997	Percent change 1992-2002
	1992	1997	2002		
ALL trucks	**59,200.8**	**72,800.3**	**85,174.8**	**23.0%**	**43.9%**
Light Trucks					
Less than 6,001 lb	50,545.7	62,798.4	62,617.3	24.2%	23.9%
6,001 to 10,000 lb	4,647.5	5,301.5	17,142.3	14.1%	268.8%
10,001 to 14,000 lb	694.3	818.9	1,142.1	17.9%	64.5%
14,001 to 16,000 lb	282.4	315.9	395.9	11.9%	40.2%
16,001 to 19,500 lb	282.3	300.8	376.1	6.6%	33.2%
19,501 to 26,000 lb	732.0	729.3	910.3	-0.4%	24.4%
26,001 to 33,000 lb	387.3	427.7	436.8	10.4%	12.8%
33,001 to 40,000 lb	232.6	256.7	228.8	10.4%	-1.6%
40,001 to 50,000 lb	338.6	399.9	318.4	18.1%	-6.0%
50,001 to 60,000 lb	226.7	311.4	326.6	37.4%	44.1%
60,001 to 80,000 lb	781.1	1,069.8	1,178.7	37.0%	50.9%
80,001 to 100,000 lb	33.3	46.3	68.9	39.0%	106.9%
100,001 to 130,000 lb	12.3	17.9	26.4	45.5%	114.6%
130,000 lb or more	4.6	5.9	6.3	28.3%	37.0%
Not reported	<50	<50	N	N	N

KEY: lb = pound; N = data do not exist.

NOTES

Average vehicle weight is the empty weight of the vehicle plus the average load of the vehicle.

Excludes vehicles owned by Federal, state, or local governments; ambulances; buses; motor homes; farm tractors; unpowered trailer units; and trucks reported to have been sold, junked, or wrecked prior to July 1 of the year preceding the 1992 and 1997 surveys and January 1, 2002 for the 2002 survey.

SOURCES

1992, 1997: U.S. Census Bureau, *1997 Economic Census: Vehicle Inventory and Use Survey: United States*, EC97TV-US (Washington, DC: 1999).

2002: U.S. Census Bureau, *2002 Economic Census: Vehicle Inventory and Use Survey: United States*, EC02TV-US (Washington, DC: 2004).

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Fleet Data by Use

Table 1-14: U.S. Automobile and Truck Fleets by Use (Thousands)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001[e]	2002[e]	2003[e]	2004[e]	2005[e]
TOTAL automobiles and trucks in fleets	U	U	U	U	U	15,257	15,570	15,869	16,879	15,530	15,196	13,642	11,985	12,128	11,884	12,274
Automobiles in fleets, total	U	U	U	U	U	9,042	9,124	9,225	9,550	7,742	7,346	6,640	5,600	5,647	5,514	5,621
Automobiles in fleets of 25 or more (10 or more cars for 1999-2001 and 15 or more cars for 2002-04)[a]																
Business[b]	2,889	2,628	2,492	1,751	1,722	1,326	1,295	1,188	1,159	3,195	2,950	2,620	930	929	873	877
Government[c]	538	504	516	401	428	1,214	1,209	1,218	1,030	885	883	734	1,360	1,420	1,200	1,200
Utilities	551	544	548	386	382	376	376	377	359	320	317	U[f]	U[f]	U[f]	U[f]	U[f]
Police	249	250	264	264	266	269	274	280	289	302	306	312	317	317	402	412
Taxi (includes vans)	141	141	140	140	141	139	130	181	190	135	136	142	148	148	156	162
Rental (includes vans and SUVs)	990	1,160	1,448	1,501	1,473	1,518	1,590	1,608	1,602	1,733	1,581	1,542	1,555	1,520	1,570	1,620
Automobiles in fleets of 4 to 24 (4 to 9 cars for 1999-2001 and 5 to 14 cars for 2002-05)[a]	U	U	U	U	U	4,200	4,250	4,373	4,921	1,172	1,173	1,290	1,290	1,313	1,313	1,350
Trucks in fleets, total	U	U	U	U	U	6,215	6,446	6,644	7,329	7,788	7,850	7,002	6,385	6,481	6,370	6,653
Trucks in fleets of 25 or more (10 or more trucks for 1999-2001 and 15 or more cars for 2002-05)[a]																
Business[d]	U	U	1,080	1,378	1,375	1,205	1,275	1,332	1,360	3,016	3,026	2,820	2,180	2,181	2,337	2,370
Government[c]	U	U	297	632	646	2,221	2,215	2,223	2,010	2,400	2,408	2,052	2,070	2,102	1,615	1,615
Utilities	U	U	593	493	487	480	482	483	459	499	498	U[f]	U[f]	U[f]	U[f]	U[f]
Other (police, taxi, etc.)	U	U	7	7	7	7	7	7	8	8	8	9	9	9	26	37
Rental trucks (not including vans and SUVs)	U	U	304	308	363	202	197	179	181	213	248	246	251	289	492	521
Trucks in fleets of 4 to 24 (4 to 9 trucks for 1999-2001 and 5 to 14 cars from 2002-05)[a]	U	U	U	U	U	2,100	2,270	2,420	3,311	1,652	1,662	1,875	1,875	1,900	1,900	2,110

KEY: SUV = sport utility vehicle; U = data are not available.

[a] The data source, Bobit Publishing, changed data collection categories in 1999 and again in 2002.

[b] Includes driver schools.

[c] Includes military vehicles and federal, state, county, and local government vehicles.

[d] Businesses with Class 1-5 trucks may include leasing, construction, plumbing, heating, food distribution, pest control, cable TV, etc.

[e] 2001-2005 data do not include employee-owned fleet information as the source has stopped publishing the data.

[f] Business and utility data have been combined in the 2002, 2003, 2004, and 2005 issues of the *Automotive Fleet Fact Book*.

SOURCE

Bobit Publishing Co., *Automotive Fleet Fact Book*, annual issues.

Annual Vehicle Distance Traveled

ANNUAL VEHICLE DISTANCE TRAVELED IN MILES AND RELATED DATA - 2008 1/
BY HIGHWAY CATEGORY AND VEHICLE TYPE

December 2009 TABLE VM-1

YEAR	ITEM	PASSENGER CARS	MOTOR-CYCLES	BUSES	OTHER 2-AXLE 4-TIRE VEHICLES 3/	SINGLE-UNIT 2-AXLE 6-TIRE OR MORE TRUCKS 4/	COMBINATION TRUCKS	SUBTOTALS: PASSENGER CARS AND OTHER 2-AXLE 4-TIRE VEHICLES	SUBTOTALS: SINGLE-UNIT 2-AXLE 6-TIRE OR MORE AND COMBINATION TRUCKS	ALL MOTOR VEHICLES 2/
	Motor-Vehicle Travel: (millions of vehicle-miles)									
2008	Interstate Rural	115,532	1,348	1,027	77,842	7,299	40,242	193,373	47,542	243,290
2007		122,183	1,420	986	82,030	7,188	42,632	204,212	49,819	256,438
2008	Other Arterial Rural	191,897	2,418	1,020	139,867	13,646	25,426	331,764	39,071	374,273
2007		204,123	2,305	1,015	145,985	13,877	26,160	350,108	40,037	393,465
2008	Other Rural	195,684	1,929	1,772	144,171	15,478	13,820	339,855	29,298	372,855
2007		203,485	1,820	1,722	148,612	15,659	14,101	352,097	29,760	385,400
2008	All Rural	503,112	5,695	3,819	361,880	36,423	79,488	864,993	115,911	990,418
2007		529,791	5,546	3,723	376,627	36,723	82,893	906,418	119,616	1,035,303
2008	Interstate Urban	262,321	2,738	1,077	169,605	10,127	30,223	431,926	40,350	476,091
2007		267,559	2,631	1,052	170,669	10,143	31,262	438,228	41,405	483,315
2008	Other Urban	850,417	6,051	2,218	577,117	37,400	33,797	1,427,534	71,197	1,507,000
2007		875,118	5,444	2,205	564,975	35,147	30,892	1,440,093	66,039	1,513,781
2008	All Urban	1,112,738	8,789	3,295	746,722	47,527	64,019	1,859,460	111,547	1,983,091
2007		1,142,677	8,075	3,257	735,644	45,290	62,153	1,878,320	107,444	1,997,096
2008	Total Rural and Urban	1,615,850	14,484	7,114	1,108,603	83,951	143,507	2,724,453	227,458	2,973,509
2007		1,672,467	13,621	6,980	1,112,271	82,014	145,046	2,784,738	227,060	3,032,399
2008	Number of motor vehicles	137,079,843	7,752,926	843,308	101,234,849	6,790,882	2,215,856	238,314,692	9,006,738	255,917,664
2007	registered 5/	135,932,930	7,138,476	834,436	101,469,615	6,806,630	2,220,995	237,402,545	9,027,624	254,403,081
2008	Average miles traveled	11,788	1,868	8,436	10,951	12,362	64,764	11,432	25,254	11,619
2007	per vehicle	12,304	1,908	8,365	10,962	12,049	65,307	11,730	25,152	11,920
2008	Person-miles of travel 6/	2,553,043	18,395	150,827	1,921,960	83,951	143,507	4,475,004	227,458	4,871,683
2007	(millions)	2,642,498	17,298	147,985	1,928,319	82,014	145,046	4,570,818	227,060	4,963,161
2008	Fuel consumed 7/	71,497,204	256,358	1,109,636	61,198,934	9,888,729	26,814,441	132,696,139	36,703,170	170,765,303
2007	(thousand gallons)	74,377,197	242,241	1,144,861	61,836,216	10,043,778	28,545,442	136,213,413	38,589,220	176,189,735
2008	Average fuel consumption per	522	33	1,316	605	1,456	12,101	557	4,075	667
2007	vehicle (gallons) 7/	547	34	1,372	609	1,476	12,853	574	4,275	693
2008	Average miles traveled per	22.6	56.5	6.4	18.1	8.5	5.4	20.5	6.2	17.4
2007	gallon of fuel consumed 7/	22.5	56.2	6.1	18.0	8.2	5.1	20.4	5.9	17.2

1/ The 50 states and the District of Columbia report travel by highway category, number of motor vehicles registered, and total fuel consumed. The travel and fuel data by vehicle type and stratification of trucks are estimated by the Federal Highway Administration (FHWA). Estimation procedures include use of State supplied data, the 2002 Census of Transportation Vehicle Inventory and Use Survey (VIUS), and other sources.
2/ Totals by highway category are from table VM-2. Some changes between rural and urban roadways can be attributed to 2002 census boundary changes.
3/ Other 2-Axle 4-Tire Vehicles which are not passenger cars. These include vans, pickup trucks, and sport/utility vehicles.
4/ Single-Unit 2-Axle 6-Tire or More Trucks on a single frame with at least two axles and six tires.
5/ Truck registration figures are from tables MV-1 and MV-9 with truck distribution estimated by the FHWA.
6/ Vehicle occupancy is estimated by the FHWA from the 2001 National Household Travel Survey (NHTS); For heavy trucks, 1 motor vehicle miles travelled = 1 person-miles traveled.
7/ Total fuel consumption figures are from tables MF-21 and MF-27. Distribution by vehicle type is estimated by the FHWA based on miles per gallon for both diesel and gasoline powered vehicles using State-supplied data, the 2002 VIUS, and other sources with nominal inputs for motorcycles and buses.

Vehicle Miles by Lane Mile Class

Table 1-33: Roadway Vehicle-Miles Traveled (VMT) and VMT per Lane-Mile by Functional Class

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Urban VMT, total (millions)	**1,627,618**	**1,663,773**	**1,686,642**	**1,727,596**	**1,805,508**	**1,892,265**	**1,951,870**	**1,977,047**	**1,994,519**	**1,983,091**
Interstate	383,259	393,465	399,986	408,618	432,633	454,385	469,070	477,283	483,315	476,091
Other arterials[a]	878,153	900,392	913,936	937,357	973,936	1,020,089	1,048,219	1,060,098	1,068,130	1,062,226
Collector	131,603	135,372	137,921	141,874	153,751	162,108	168,038	173,210	174,661	175,389
Local	234,603	234,544	234,799	239,747	245,188	255,683	266,543	266,456	268,413	269,385
Rural VMT, total (millions)	**1,062,623**	**1,083,152**	**1,110,697**	**1,128,160**	**1,085,385**	**1,070,248**	**1,037,937**	**1,037,069**	**1,035,303**	**990,418**
Interstate	260,166	268,180	273,619	279,962	269,945	266,996	258,790	257,913	256,438	243,290
Other arterials[a]	413,320	420,599	427,482	433,805	416,596	409,944	398,932	394,499	393,465	374,273
Collector[b]	264,453	267,231	272,109	275,007	263,662	260,931	251,587	251,375	251,514	241,158
Local	124,684	127,142	137,487	139,386	135,182	132,377	128,628	133,282	133,886	131,697
Urban VMT per lane-mile, total (thousands)	**858**	**869**	**857**	**861**	**856**	**860**	**862**	**856**	**851**	**829**
Interstate	5,229	5,323	5,370	5,440	5,436	5,479	5,455	5,427	5,414	5,245
Other arterials[a]	1,950	1,974	1,997	2,025	2,012	2,019	2,001	1,989	1,977	1,923
Collector	706	718	728	743	741	745	745	747	747	723
Local	198	196	189	188	183	184	187	183	181	179
Rural VMT per lane-mile, total (thousands)	**169**	**172**	**177**	**179**	**175**	**174**	**170**	**170**	**169**	**163**
Interstate	1,939	1,993	2,032	2,080	2,070	2,088	2,061	2,074	2,076	1,981
Other arterials[a]	766	778	788	797	(R) 780	771	753	744	742	705
Collector[b]	187	189	192	195	190	189	183	184	184	177
Local	30	30	33	33	33	32	32	33	33	32

[a] Urban other arterials include other freeways and expressways, other principal arterials, and minor arterials. Rural other arterials include other principal arterials and minor arterials.

[b] Collector is the sum of major and minor collectors (rural only).

NOTES

See table 1-6 for estimated highway lane-miles by functional class.

Component values may not add to totals due to rounding.

SOURCES

1980-94: U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics Summary to 1995*, FHWA-PL-97-009 (Washington, DC: July 1997), table VM-202, available at www.fhwa.dot.gov/policy/ohpi as of Mar. 18, 2009.

1995-2008: U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics* (Washington, DC: Annual issues), table VM-2, available at www.fhwa.dot.gov/policy/ohpi as of Mar. 3, 2010.

Lane-miles:

1980-95: U.S. Department of Transportation, Federal Highway Administration, Office of Highway Information Management, unpublished data, 1997, table HM-260.

1996-2008: U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics* (Washington, DC: Annual issues), table HM-60, available at www.fhwa.dot.gov/policy/ohpi as of Mar. 3, 2010.

The Replacement for Aging Plants

	Replacement Costs per Watt	MW over 40 Years	Replacement Costs
Hydroelectric Conventional	$2.29	58,258	$133,410,820,000
Coal	$2.22	141,574	$314,294,280,000
Other Gases	$2.60	1,000	$2,600,000,000
Pumped Storage	$2.29	4,104	$9,398,160,000
Other	$1.40	300	$420,000,000
Wood and Wood Derived Fuels	$3.84	2,321	$8,912,640,000
Nuclear	$3.82	6,903	$26,369,460,000
Petroleum	$0.98	20,049	$19,648,020,000
Natural Gas	$0.69	78,541	$54,193,290,000
Geothermal	$1.75	110	$192,500,000
Other Biomass	$2.60	192	$499,200,000
Wind	$1.97	-	-
Solar Thermal and PV	$6.17	-	-

45% of the Total

fleet ENERGY

http://www.eia.gov/oiaf/aeo/assumption/pdf/electricity.pdf#page=3

Cost of the Generation Fleet (the Competition)

	Replacement Costs per Watt	O&M in $/kWh	MW of Plants over 40
Hydroelectric Conventional	$2.29	$0.025	58,258
Coal	$2.22	$0.047	141,574
Other Gases	$2.60	$0.000	1,000
Pumped Storage	$2.29	$0.025	4,104
Other	$1.40	$0.073	300
Wood and Wood Derived Fuels	$3.84	$0.069	2,321
Nuclear	$3.82	$0.005	6,903
Petroleum	$0.98	$0.021	20,049
Natural Gas	$0.69	$0.037	78,541
Geothermal	$1.75	$0.000	110
Other Biomass	$2.60	$0.000	192
Wind	$1.97	$0.000	-
Solar Thermal and PV	$6.17	$0.000	-

Gas + Wind is less than Gas + Coal

fleet ENERGY

http://www.eia.gov/oiaf/aeo/assumption/pdf/electricity.pdf#page=3

Competitive Landscape

Competition is from existing natural gas and coal power plants. Those power plants could run more efficiently with higher revenue per hour of operation when combined with energy storage.

Generation Type	to Build per Watt	to Operate per kWh
Coal	**$2.22**	**$0.047**
Natural Gas	**$0.69**	**$0.037**
Wind	**$1.97**	**$0.000**
Photovoltaic	**$6.17**	**$0.000**
Fleet Energy	**$0.89**	**$0.0043***

Storage is an additional grid cost yet improves energy efficiency thereby lowering the kWh costs of all resources.

** Losses only and according to FEC's financial model under present 6 month average Ancillary Services Pricing in PJM of $13.75 / MWh*

Only Two Small Services Represent $1.5B in Annual Market Potential

	2009 Ft Collins (PRPA)	PJM Interconnect (51 Million People)	United States (Extrapolated from PJM)	Global (Extrapolated from PJM)
Total of All Services	$84,907,618	$26,551,300,000	$160,350,544,795	$730,975,078,099
Energy Service	$46,237,974	$11,163,100,000	$67,417,006,572	$307,327,622,162
Capacity Service	$36,252,765	$8,752,400,000	$53,615,237,018	$244,410,782,117
Operating Service	$1,339,949	$323,500,000	$1,953,704,762	$6,375,277,816
Regulation Service	$945,627	$228,300,000	$1,398,514,534	$8,906,171,741
Spinning Service	$131,302	$31,700,000	$191,444,949	$872,722,238

FEC's Operations are Highly Competitive in These Two Services

http://www.prpa.org/

http://pjm.com/about-pjm/who-we-are/~/media/about-pjm/newsroom/2009-financial-report.ashx