Energy Efficiency & Net Zero Energy Workshop

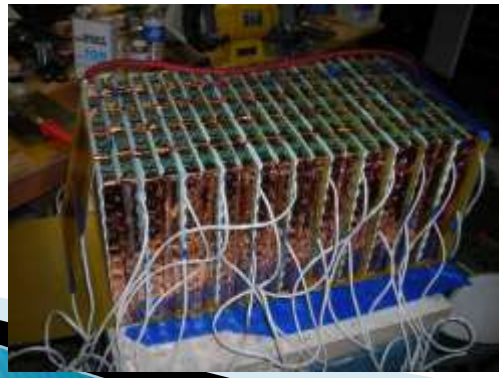
Lithium Storage, EV Charging and the Smart Grid

Mike Willmon, P.E., CEM

March 2011

Part 1
Lithium Batteries

Lithium Battery Storage Systems



Overview: Definitions

- Capacity is the measure how much energy a cell can hold usually measured in Amp-Hours.
- Energy Density is the measure of energy a cell will hold, usually in Watt-Hours or Kilowatt-Hours, per unit of mass typically in Kilograms
- Power Density is the measure of power a cell can deliver, usually in Watts or Kilowatts, per unit of mass typically in Kilograms. This is sometimes mistakenly referred to as Discharge Rate.

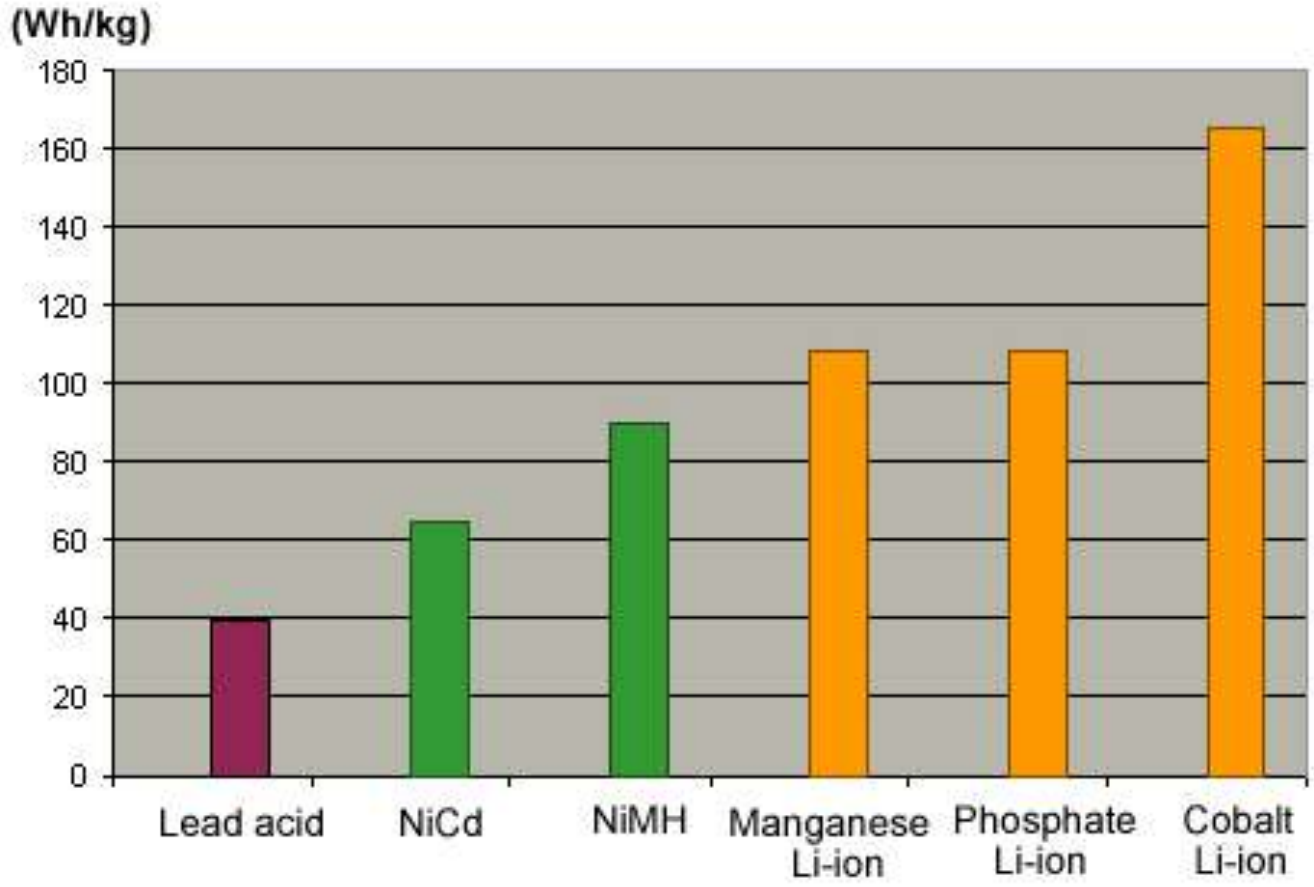
Explanation of Discharge Rate or C Rate

- If the capacity of a cell is 100 AH then a similar method of advertising its power capability is to state how much current in relation to its AH capacity the cell can produce.
- A 100AH cell that can produce 100 Amps is said to have a 1C power or discharge rating.
- Another 100AH cell that can produce 1000 Amps is said to have a 10C power or discharge rating.

Analogy

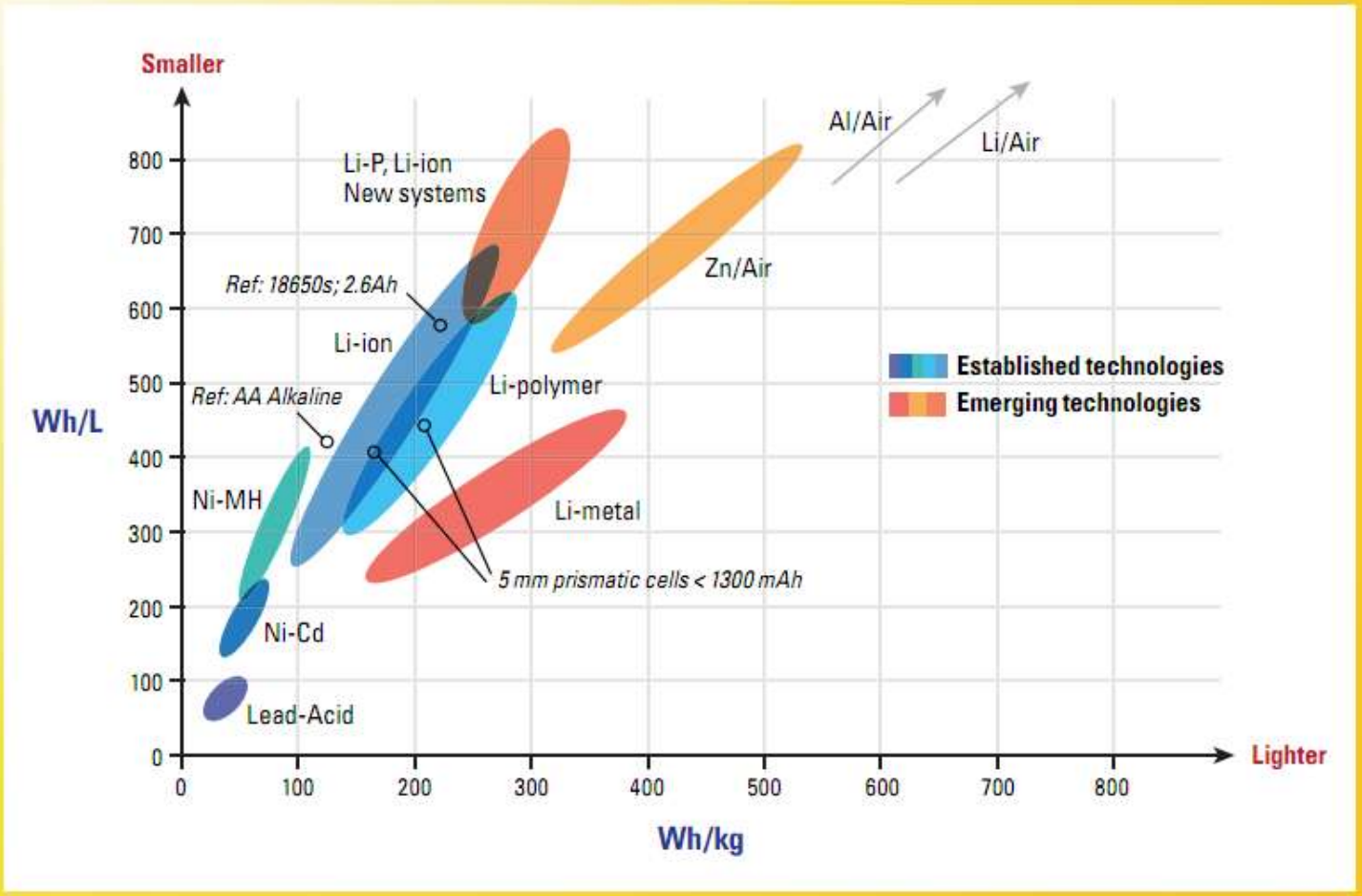
- In keeping with the water pipe theory of electronics, Energy content is like the size of a water bottle. Power capability is like the size of the opening in the neck of that bottle. A small bottle with a large neck can deliver its contents very rapidly. A large bottle with a small neck will be able to deliver more content, but will take longer to do it through the smaller opening.

Energy Density



nexergy

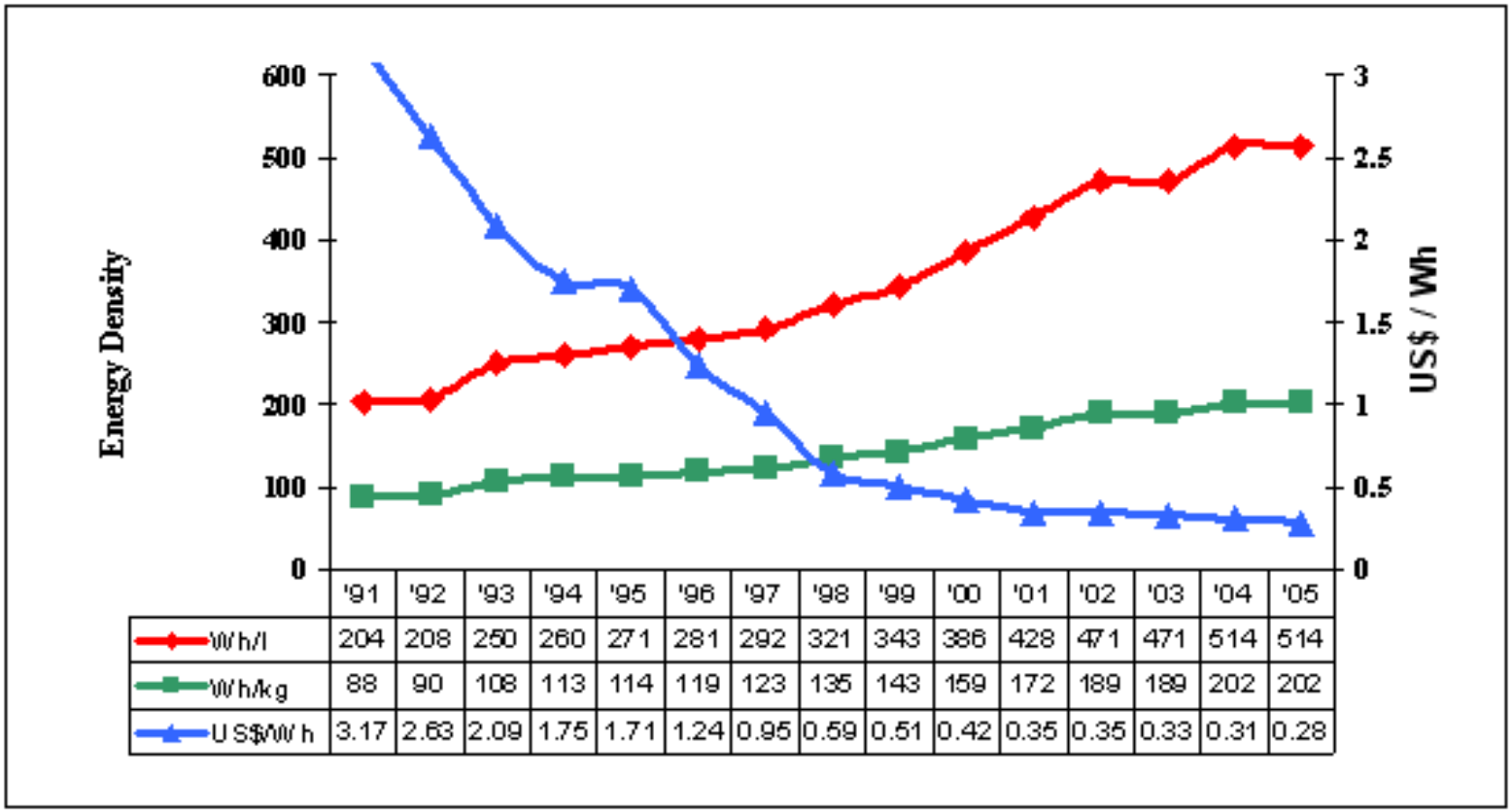
Comparison of Energy Densities for Various Chemistries



More information on battery chemistry and battery pack design can be found at the Nexergy Web site.

1-800-537-9602
www.nexergy.com

Lithium Battery Pricing



	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05
Wh/l	204	208	250	260	271	281	292	321	343	386	428	471	471	514	514
Wh/kg	88	90	108	113	114	119	123	135	143	159	172	189	189	202	202
US$/Wh	3.17	2.63	2.09	1.75	1.71	1.24	0.95	0.59	0.51	0.42	0.35	0.35	0.33	0.31	0.28

References: The Freedonia Group, Inc. www.freedoniagroup.com
Barry Huret, president of battery consulting company Huret Associates Inc. in Yardley, Pa, USA (www.huret.com)

Which cells do I use?

- Is the application
  - Weight constrained
  - Space constrained
  - Energy capacity constrained
  - Power capability constrained
  - $$$ Cost Constrained $$$
  - Availability constrained
- First define your ultimate requirement

Which cells do I use?

- Power tools
  - High power
  - Long run time
  - Light weight
- Typically power tools are using small cylindrical cells such as Sony, Sanyo, Emoli or A123 Systems M1 cells which are 18650 (18mm dia and 650 mm in length)

Which cells do I use?

Common A123 Systems Cell sizes

- ANR26650M1A
- APR18650M1A
- APR18650M1HDA
- AHR32113-Ultra-A
- AHR32113-Ultra-B
- AHR32157-M1-A
- AHR32157-M1-B
- AHP68150202-M1-A
- AHP68150202-M1-B
- AHP70161227-M1-A
- AHP70165227-M1-A
- APP72161227-M1-A
- AHR18700-M1-ULTRA-F1
- AHR26700-M1-ULTRA-F1

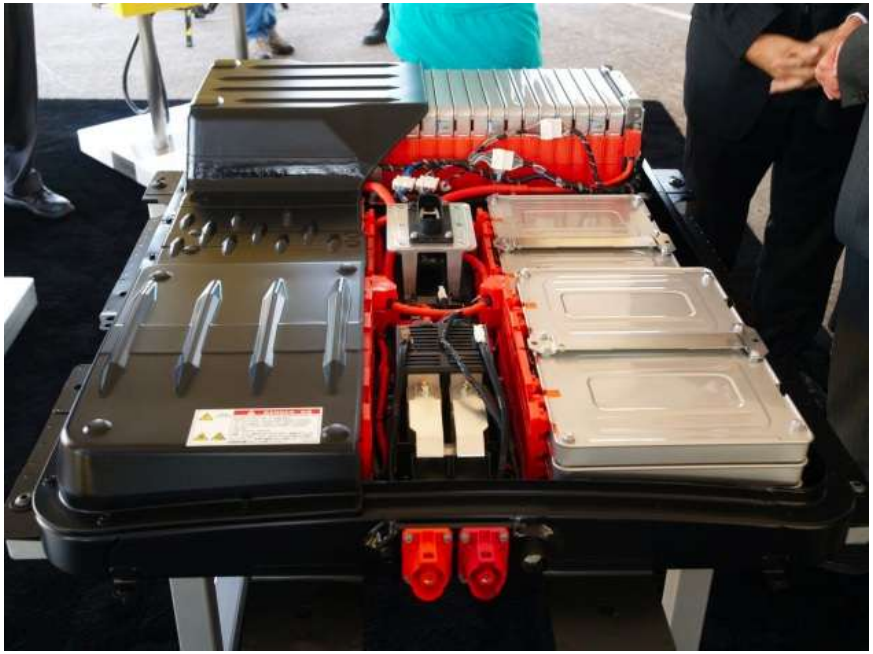
Which cells do I use?

- Transportation (EV's, Motorcycles, Bikes)
  - Long run time
  - Moderate power
  - Weight
  - Cost
- The big trade off in this design is Power for Energy. You must carefully balance performance versus range.

Which cells do I use?

- Large EV's consider large format Prismatic cells.
- Motorcycles might consider some of the smaller prismatic cells -OR- larger size cylindrical cells to meet size or pack shape constraints.
- Bicycles consider running modular packs of cylindrical cells

Which cells do I use?



Which cells do I use?

Which cells do I use?

Which cells do I use?

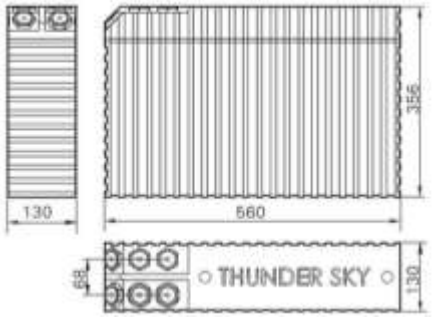
- Reserve/Home Power
  - High Energy
  - Lower Power
  - Cost
- Unless you have really high power requirements like large water heaters or power tools, high energy/lower power density large format prismatic cells will be more cost effective and easier to assemble

Which cells do I use?

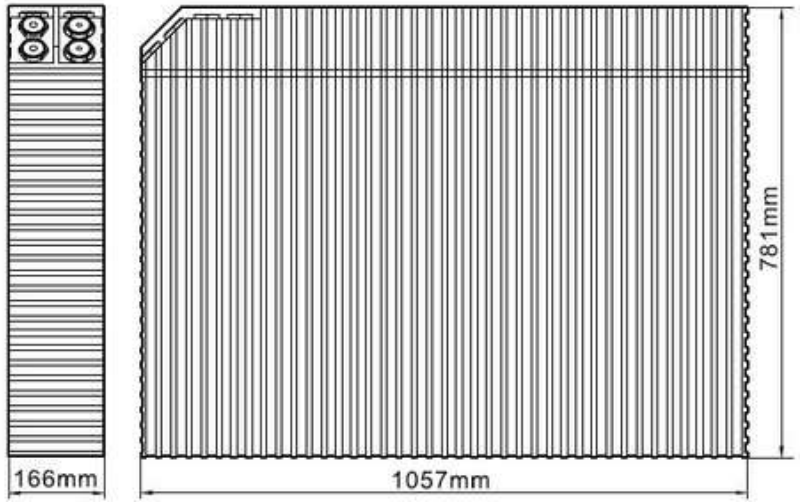
200 AH cells
7.3Kg each

16 each 200AH Cells
Nominal 48Vdc
Pack weight 255 lbs
9.6KWH pack
~$4,600 incl. BMS

1000 AH cell
35Kg each



~$1300 each



175Kg each ~$9100 each

Part 2
EV Charging

EV Charging Systems

Technical Standards Background

- In the early 1990's the EV forum's Charging Systems task force generated J1772™ & J2293 along with corresponding UL documents and NEC Article 625.
- More recently, the HEV Committee task forces have updated J1772™, re-issued J2293 and started J2836™ & J2847 for utility communications.
- Thru SAE & IWC, updates have been presented to the NEC's Code Panel to include PHEV effects (2011 version).

Vehicle Design & Interface
Technical Requirements

- SAE (Vehicle aspects defining EVSE Electric Vehicle Supply Equipment)
  - J1772™ - SAE Electric Vehicle and Plug In Hybrid Electric Vehicle Conductive Charge Coupler (Jan 2010)
  - J2293 - Energy Transfer System for Electric Vehicles
    - Part 1: Functional Requirements and System Architectures
    - Part 2: Communication Requirements and Network Architecture

  Note: J2293 is additional communication,
  Required for DC energy to the vehicle,
  Optional for AC

Vehicle Design & Interface
Technical Requirements

- SAE (Vehicle aspects)

New documents for communications

  - J2836™ - TIR - General info including Use Cases
  - J2847 – RP – Detail information
    - 1 – Utility programs
    - 2 – Simplified J2293
    - 3 – Reverse Energy Flow
    - 4 – Diagnostics
    - 5 – Vehicle Manufacturer Specific

Vehicle Design & Interface
Technical Requirements

- AC Level 1 Charging
  - 120V AC charging from standard 15 or 20 amp NEMA outlet, on-board vehicle charger (~1.9kw)
- AC Level 2 Charging
  - 208 – 240 AC charging up to 80 amps, on-board vehicle charger (~19kw)

- AC Level 3 >20 Kw -- Proposed
- DC Level 1 (20kW) ,2 (80Kw) and 3 (>80Kw) Fast Charging
  - Off-board charger connects directly to vehicle high voltage battery bus
  - Charger controlled by vehicle which allows for extremely high power transfer (>100kw) and thus faster recharge times (minutes instead of hours)
  - Actual charge rate limited by battery chemistry, infrastructure and other factors

Battery Charge Time

			Circuit Size and Power Delivered to Battery			
EV Configuration	Battery Size (KWh)	Approximate Battery Only Range	120 VAC, 15 amp 1.1KW	120VAC, 20 amp 1.5KW	220 VAC, 40 amp 6 KW	440 VAC, 85 amp 55KW
PHEV-10	4	12 -16 miles	3 h 50 m	2 h 40 m	40 m	-
PHEV-20	8	24-32 miles	7 h 20 m	5 h 20 m	1 h 20 m	-
PHEV-40	16	48-64 miles	14 h 30 m	10 h 40 m	2 h 40 m	17 m
BEV	24	70-95 miles	21 h 48 m	16 h 00 m	4 h 00 m	26 m
BEV	35	110-140 miles	31 h 50 m	23 h 20 m	5 h 50 m	38 m
PHEV Bus	50	30-40 miles	-	-	8 h 20 m	55 m

Power calculated by multiplying

the Voltage x the NEC circuit derated current capacity x 0.85 efficiency

Examples of Level 1 EVSE

Examples of Level 2 EVSE Hardware







Side Note

- Folks with conversion that do not yet have J1772 inlets or J1772 aware chargers are building converters so they may still charge their EV's at public stations. The benefit is that they may still be charging from a NEMA 14-50 at home.

Examples of DC Fast Charging

Certification
UL listed components and systems

- UL (Off-board equipment)
  - UL 2202 – Electric Vehicle (EV) Charging System Equipment
  - UL 2231 – Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits
    - Part 1: General Requirements
    - Part 2: Particular Requirements for Protection Devices for Use in Charging Systems
  - UL 2251 – Plugs, Receptacles and Couplers for Electric Vehicles
  - UL 2594 – Cord Set

Regulations
National Building Codes

- National Electric Code (Premise aspects Wiring and Installations)
  (Article NEC 625) "Electric Vehicle Charging System"
  Scope
  The provisions of this article cover the electrical conductors and equipment external to an electric vehicle that connect an electric vehicle to a supply of electricity by conductive or inductive means, and the installation of equipment and devices related to electric vehicle charging.
  - Article 625 – Electric Vehicle Charging System
    - I – General
    - II – Wiring Methods
    - III – Equipment Construction
    - IV – Control & Protection
    - V – EV Supply Equipment Locations

      Note: NEC is updated every 3 years and the 2011 proposals were submitted September, 2009.

NEC Article 625

- History of NEC 625
  - Introduced into NEC in 1995
  - Revised in:
    - 2002: Allowed longer cable lengths with Cable Management Systems & options for ventilation indoors
    - 2005: Included Neighborhood electric vehicles (Low Speed Vehicles), addressed Loss of Primary Power (backfeed), and Interactive Systems.
    - 2008: Clarified requirements for Disconnecting Means
  - You have to buy a copy from NFPA
  - Each jurisdiction can adapt whatever year code they chose

NEC Article 625 (cont)

- Key Issues Addressed in 625
  - EV Coupler
    - Grounding Requirements (make first, break last)
    - Polarization – only fits one way
    - Unique – not interchangeable with other wiring devices
    - Constructed to prevent contact with live parts
  - EVSE – Fixed Wiring or Cord and Plug Connected
    - Permits 125VAC, 15 or 20Amp, single phase EVSE (cord-set) to be cord and plug connected
    - For 240VAC - must be permanently connected and fastened in place (hard-wired) unless it meets the following:
      - 625.18 Interlock Requirements
      - 625.19 Automatic de-energization of cable
      - 625.29 Indoor sites
      - Listed as suitable for the purpose (UL)

NEC Article 625 (cont)

- Interlock requirements (625.18)
  - Requires EVSE to be provided with interlock that de-energizes EV connector & cable when EV connector is disconnected from the vehicle.

  Exception: Not required for portable cord and plug connected EVSE intended for connection to a 15A or 20A, 125VAC, single phase receptacle.

- Automatic De-energization of cable (625.19)
  - EVSE or cable – connector combination requires automatic means to de-energize cable conductors & EV connector when subjected to strain that could rupture or separate cable from EVSE or result in exposure of live parts.

  Exception: Not required for portable cord and plug connected EVSE intended for connection to a 15A or 20A, 125VAC, single phase receptacle.

NEC Article 625 (cont)

- Personnel Protection against electric shock (625-22)
  - EVSE shall be provided with listed system of protection against electric shock of personnel.
  - For cord and plug connected EVSE, interrupting means of the listed system shall be integral part of attachment plug or located (in-line) in power supply cable within 12 inches of plug.

- Loss of Primary Source – Backfeed (625.25)
  - EVSE requires means to prevent electrical energy from feeding back into premise wiring system in the event of a power failure or other loss of voltage from utility.

  Exception: EVSE used for interactive systems per Article 625.26

NEC Article 625 (cont)

- Interactive Systems – Optional standby source (625.26)
  - EVSE or other parts of the systems, either on-board or off-board the vehicle, specifically Listed and identified for use as optional standby system, or electrical power source, or intended for bi-direction power feed shall be Listed and suitable for the purpose.

- Ventilation (625.29)
  - Ventilation not required for non-vented storage batteries (SAE J1718) or EVSE Listed or labeled and marked for indoor charging without ventilation.
  - Where venting batteries are used, mechanical ventilation requirements are provided in 625.29.

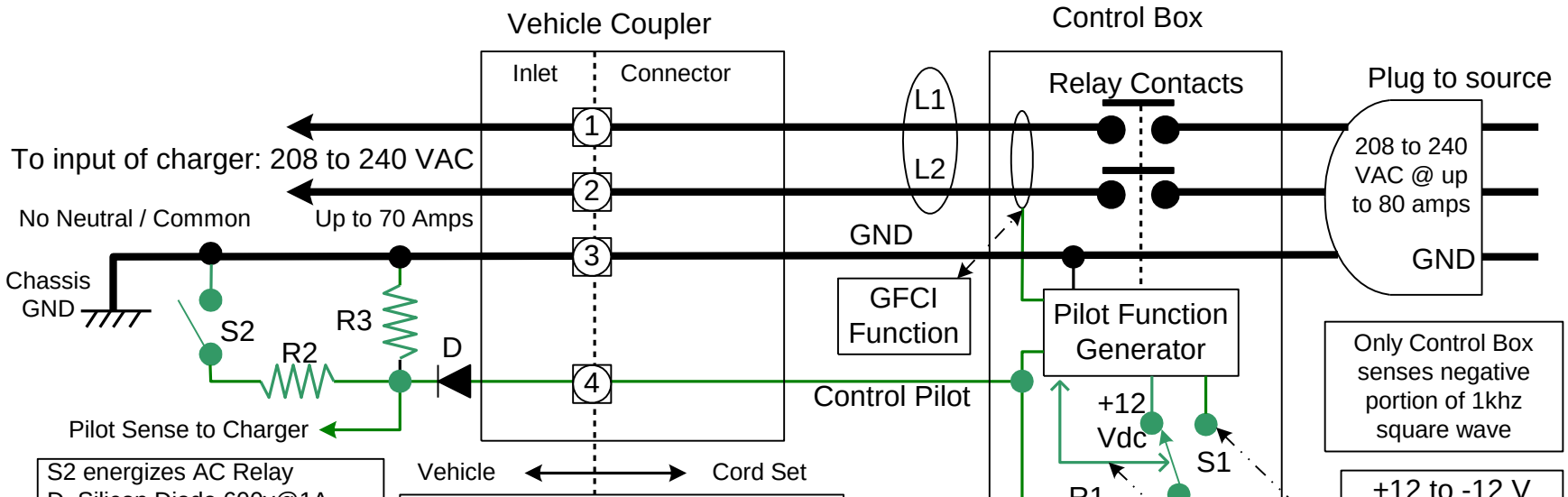
Future changes to NEC Article 625

- Add Plug-in Hybrid Electric Vehicles (PHEV)

- Expand to include “Smart” systems for power transfer & information exchange between utility, EVSE and PEV.

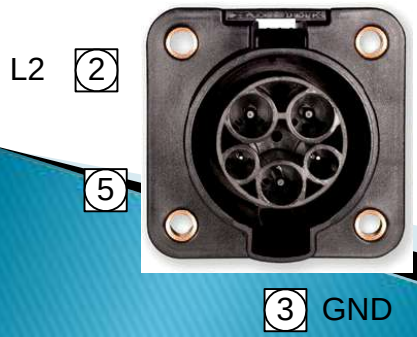
- Identify generic battery types & other energy storage types or maximum sizes of battery packs (PHEVs) where emission of hydrogen or other flammable gases do not occur, or do not exceed 25 percent of the lower flammable limit.

SAE J-1772 Electrical Configuration



Voltages on Pilot

Unplugged +12V dc	Main Contactor OPEN/Off
Connected +9 to -12v square wave	Main Contactor OPEN/Off
S-2 closed +6 (or +3) to -12V square wave	Main Contactor Energized/On



Not Shown in Drawing is proximity sensor control line to shut off EVSE in event cord is separated from vehicle

Part 3
Grid Interface

What is the Smart Grid?

"The Smart Grid is a transformative set of technologies and business models. With mutually supportive private and public investment and with governmental policies that accommodate entrepreneurial smart grid innovations, we can grow our economy, create new high paying jobs, and help protect our environment……..

What is the Smart Grid?

…….. The convergence of these diverse benefits represents an unparalleled opportunity for policy makers to advance an agenda based on research and development, on innovation and on economic development."

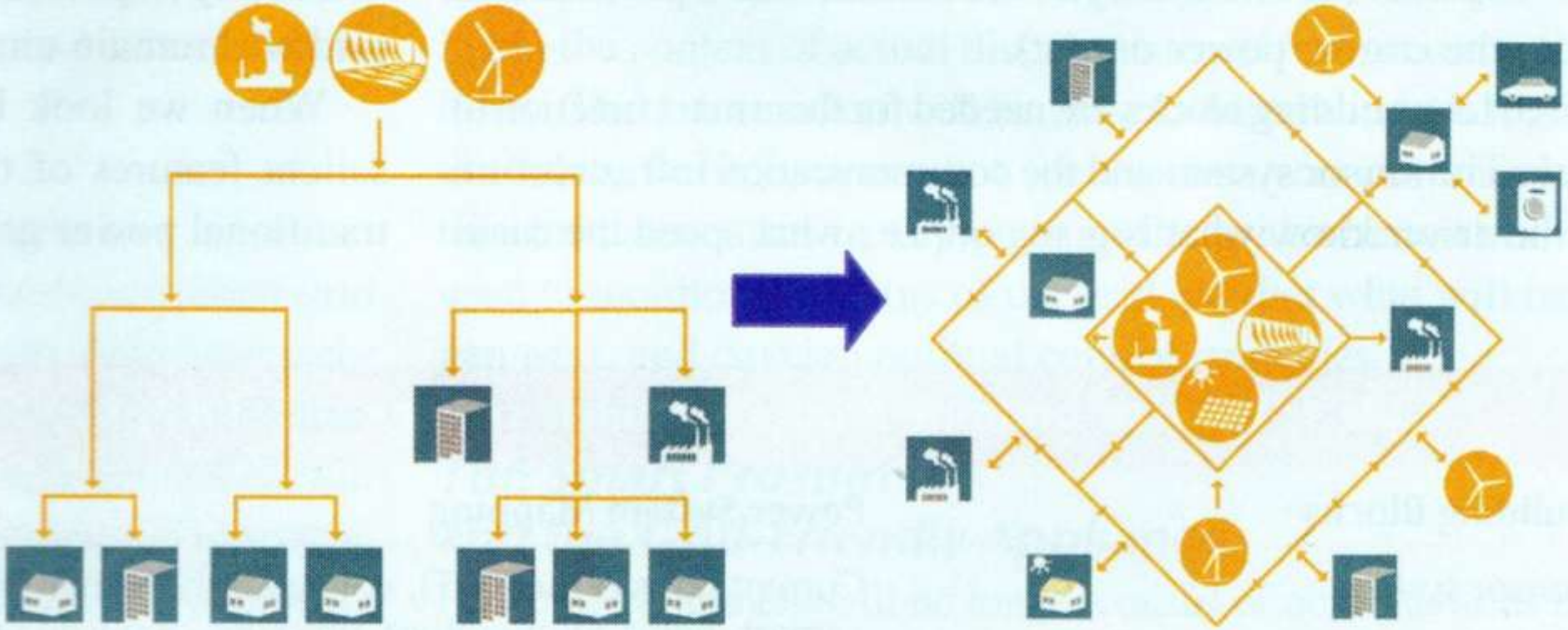
"Benefits of the Smart Grid" by Bruce Hamilton and Matthew Summy IEEE Power & Energy Magazine V9 No. 1 pp 104

Attributes of the Smart Grid

- Self Healing from power disturbance events
- Enables active participation by consumers in demand response
- Operates resiliently against both physical and cyber attacks
- Provides quality power that meets 21st century needs
- Accommodates all generation and storage options

Traditional Grid

Smart Grid



Traditional Grid	Smart Grid
Centralized Generation	Generation Everywhere
Power Flows Downhill	Power Flows from Everywhere
Utility Controls Connections	Anyone May Participate
Behavior: Predictable	Behavior: Chaotic

Vehicle-to-Grid (V2G)

V2G is a concept that allows the energy storage in EVs to be used to support the electrical grid during peak electrical loads, in times of emergency such as grid voltage support, or based on pricing economics.

V2G could also support vehicle-to-home, whereby the energy stored in the vehicle battery could supplement the home electrical requirements.

Vehicle-to-Grid (V2G)

V2G requires that the on-board vehicle charger be bi-directional (energy can flow both directions).

The EVSE at the premises must also be bi-directional and able to accommodate all of the utility requirements related to flowing energy back into the electrical grid.

V2G Communications

J2836 Objectives

Support for …

- Smart charging (active load management)
- Bi-directional energy transfer (V2G)
- Synchronize with new J1772
- New vehicle architectures: PHEV, EV and plug-in fuel cell (PFCV)
- New battery technologies and packaging methods
- New utility and customer premise equipment options
- Advanced metering infrastructure (AMI)
- Home-area networks (HAN)
- New communication options