BATTERY STORAGE:
FROM MALIGNED TO INDUSTRY DARLING

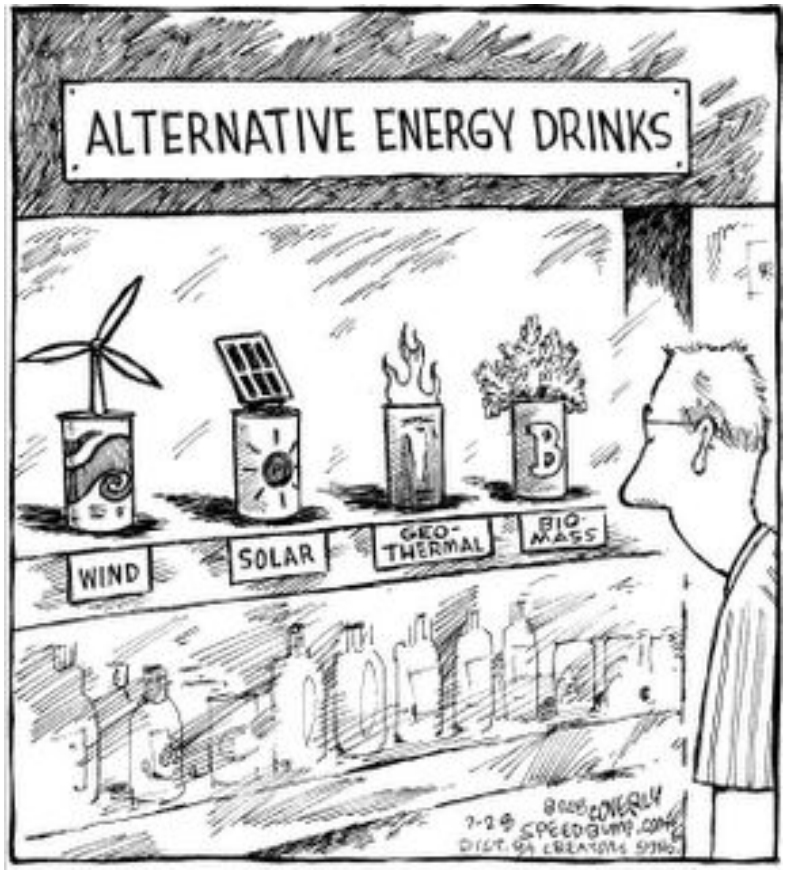
(key excerpts: for further info please contact Sol)

AEE

Sol Haroon (EE)

2018

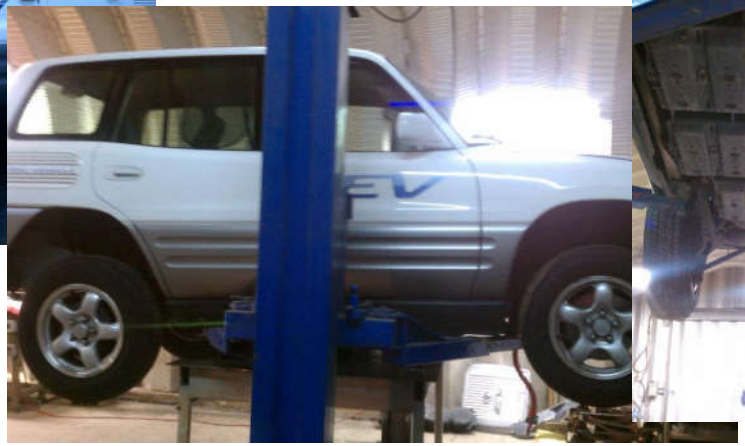
- More renewables?
- Reduce demand?
- Smarter control systems?
- Smarter grid?
- Demand side control?
- Good economics?
- Safety/accessibility?
- Scalability?
- Resiliency?
- Better distribution/penetration?

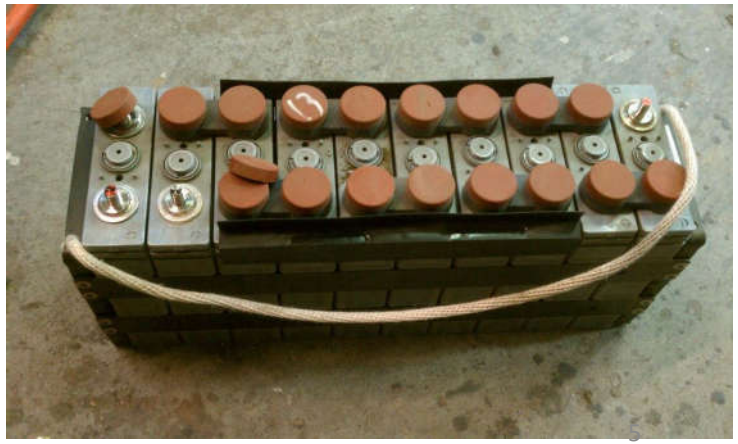


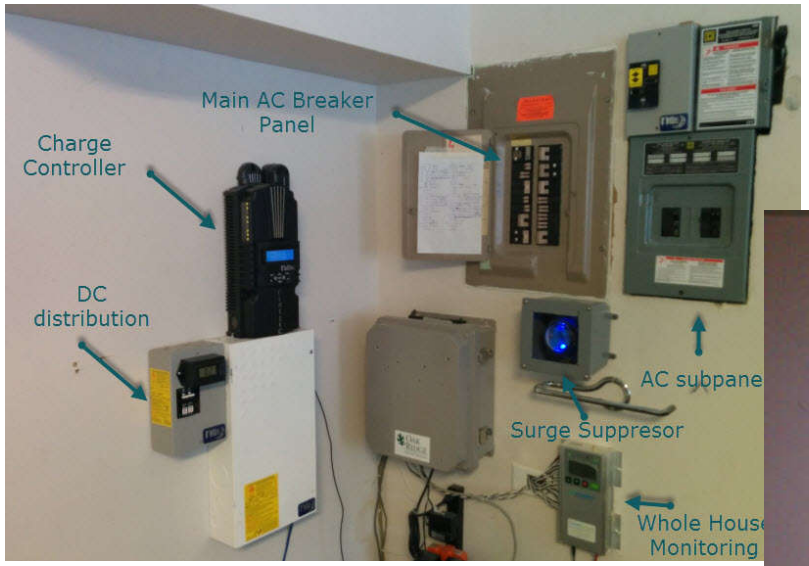
Where have we been?

What's happening now?

What's next?





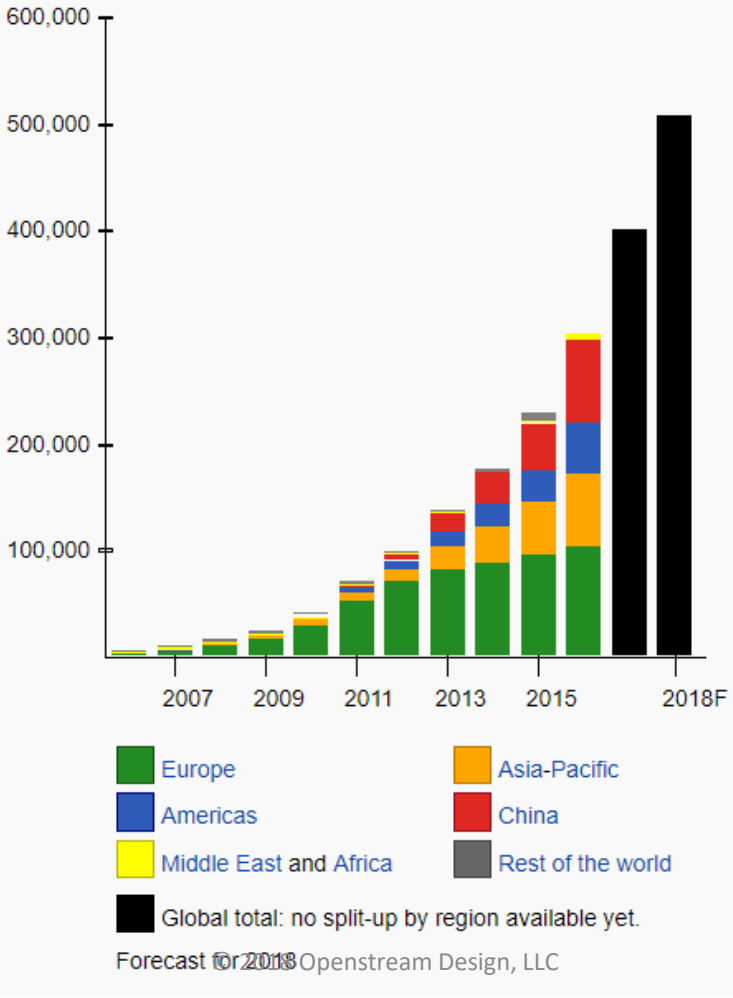


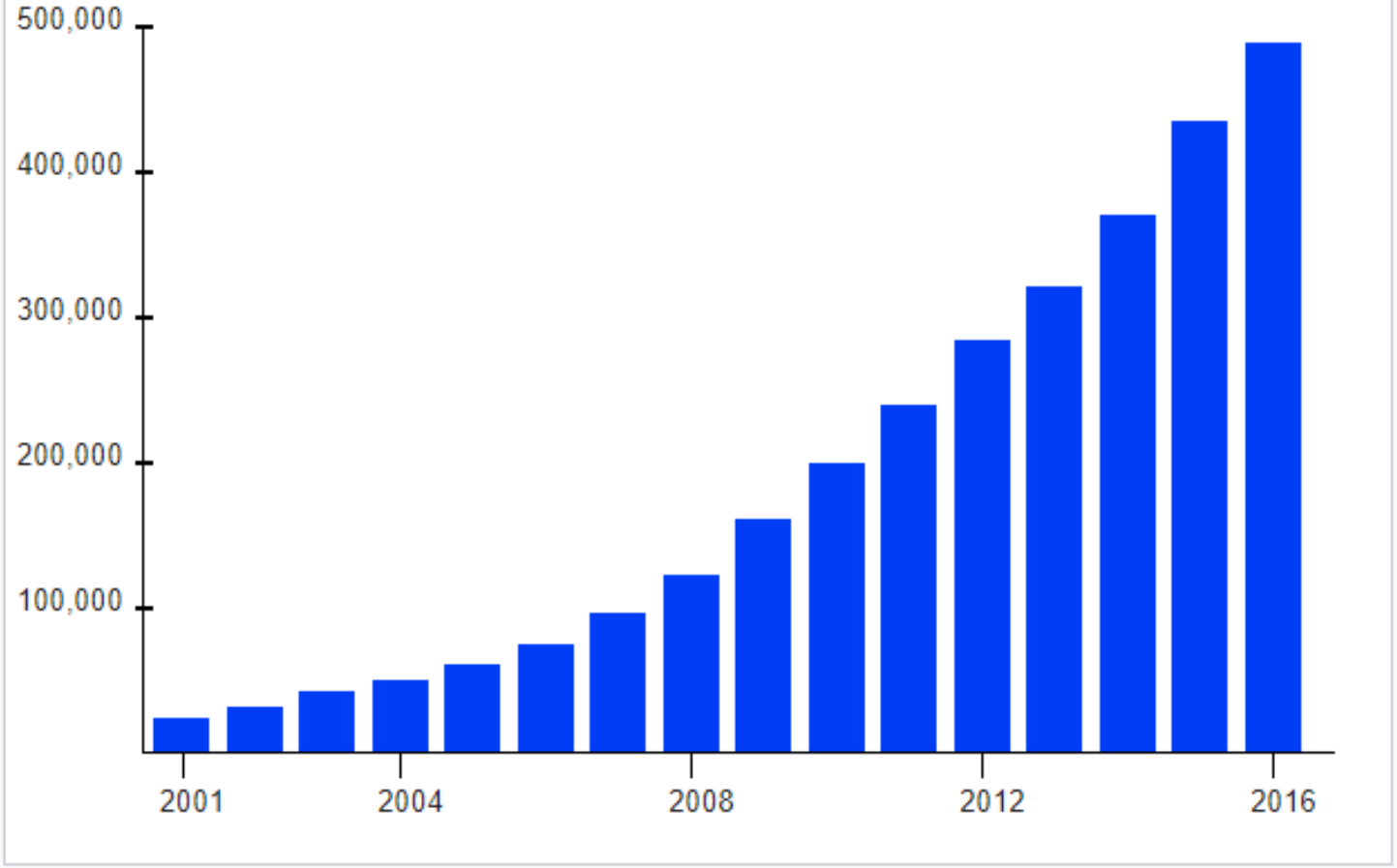
Why has storage been so hard to do?

- **Cost**
  - **Technology Options**
    - **Familiarity**
      - **Comfort and safety**
        - **Data acquisition/Load Profiles**
          - **Scalability**
            - **Lack of Control Systems**
              - **Technical Complexity**

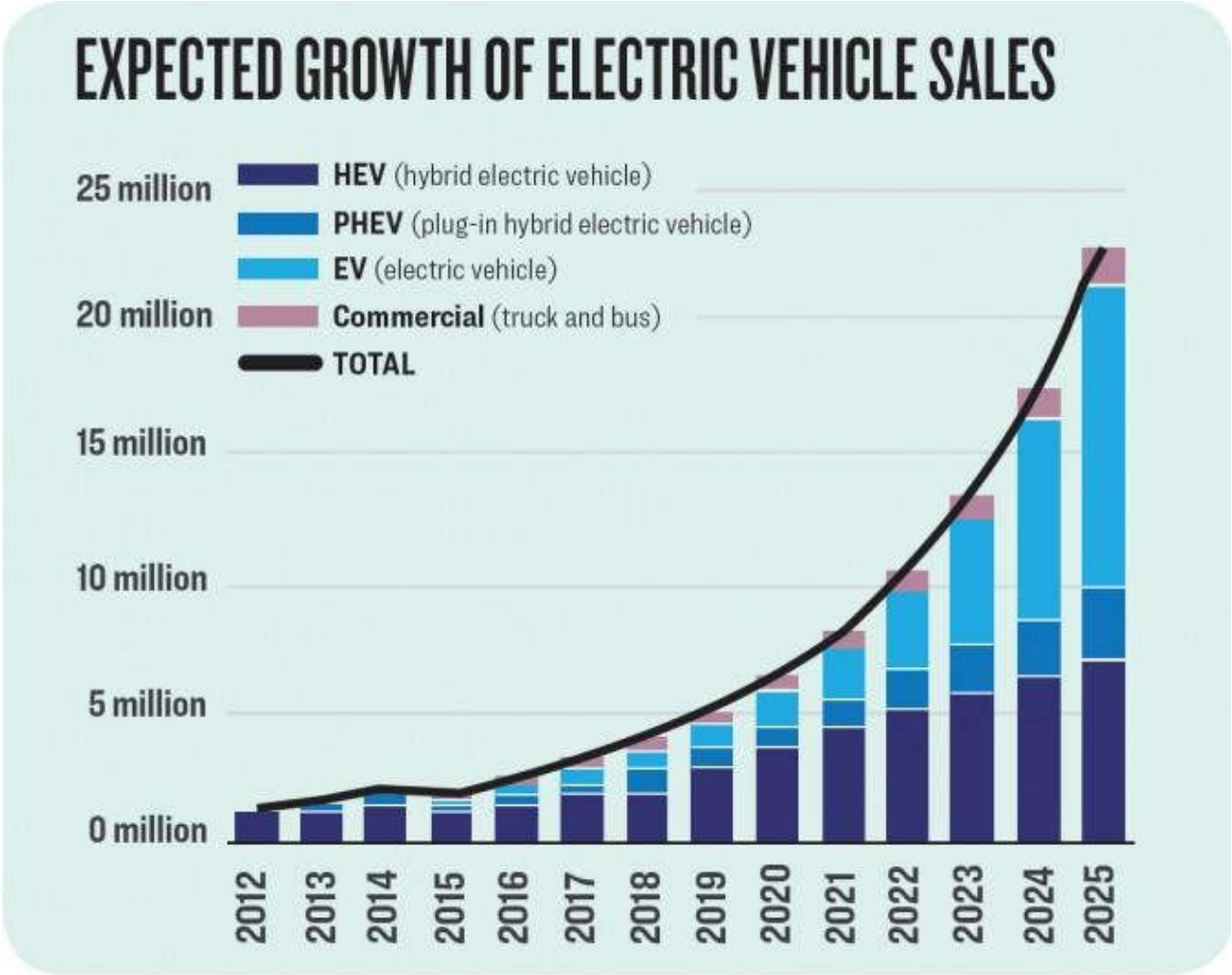
Worldwide growth of photovoltaics

Cumulative capacity in megawatts [MW_p] grouped by region[1][2][3][4][5]
Split-up for 2016 estimated from IEA.[6]





Cumulative installed wind capacity in megawatts since 2001[1]



LED Lighting

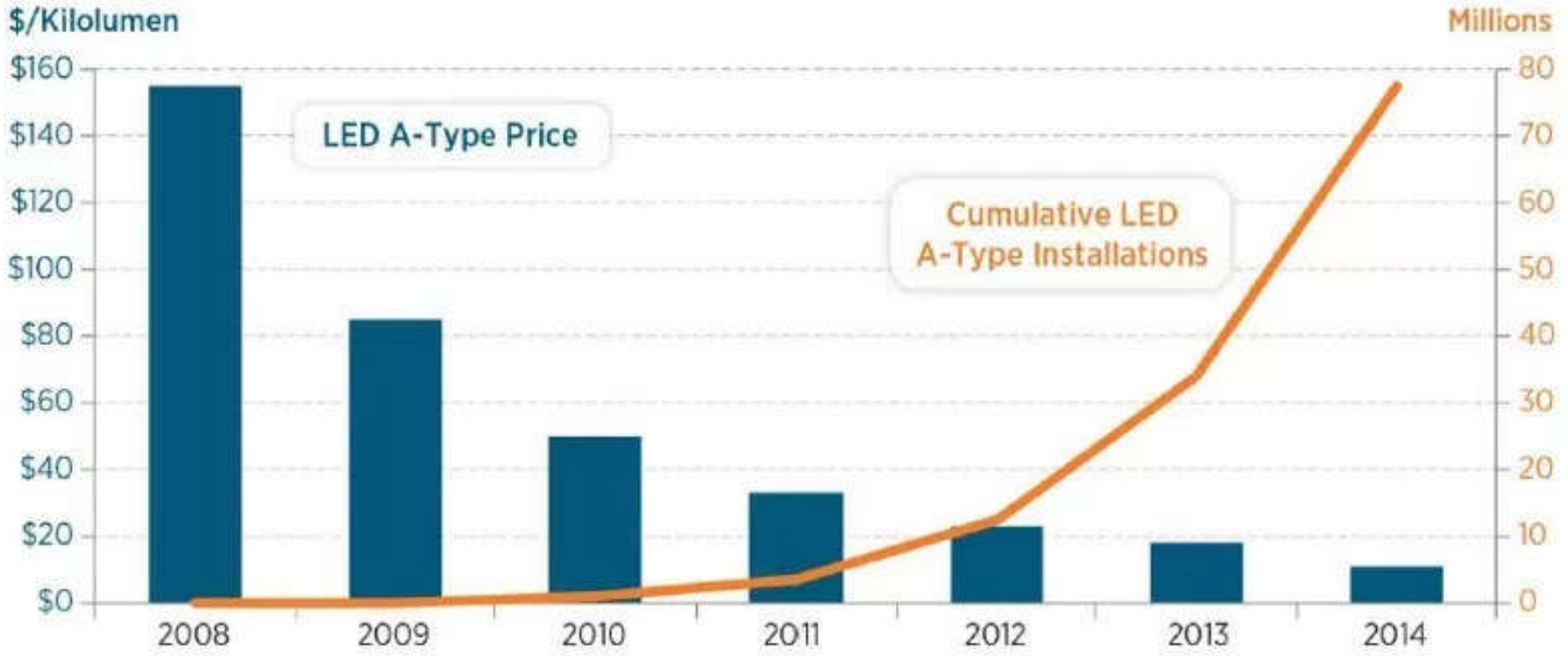
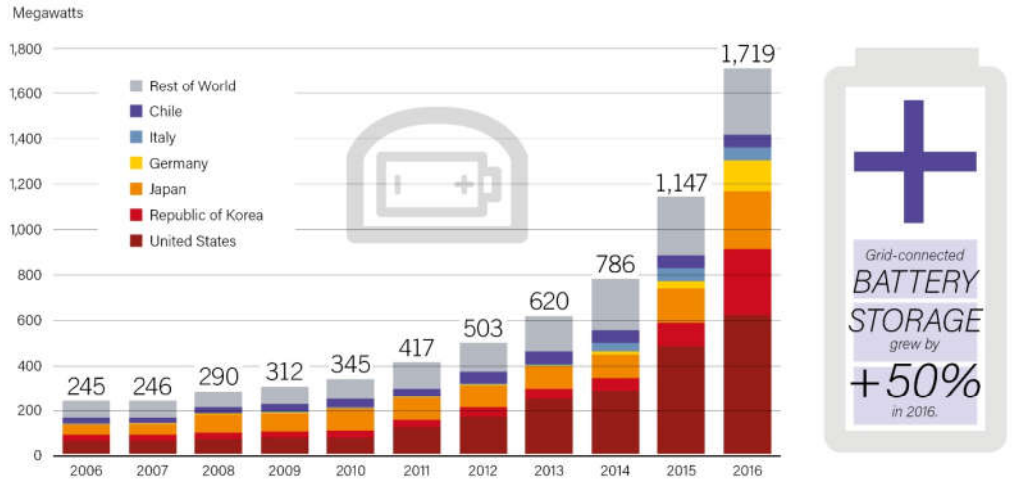
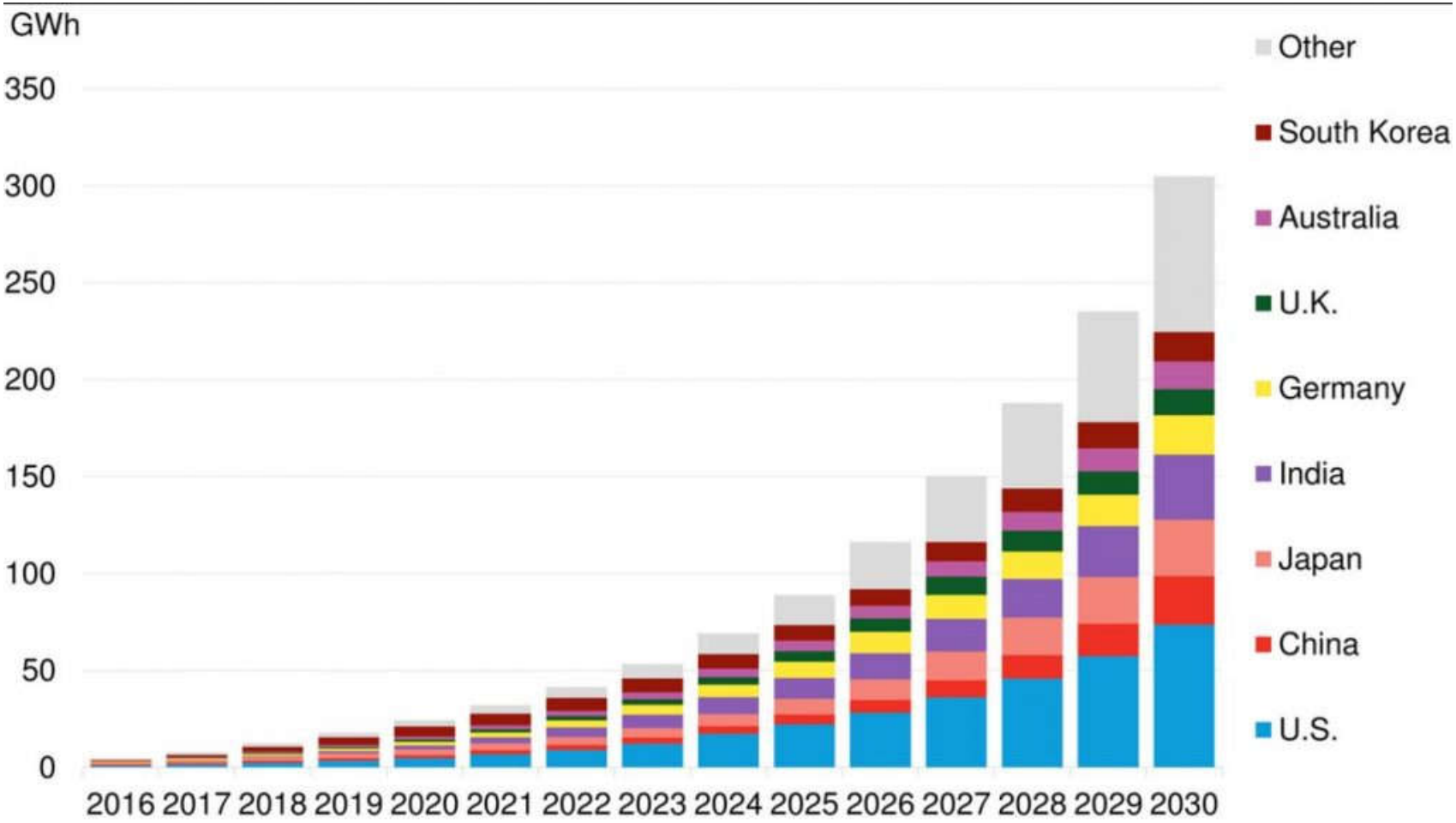


Figure: 51

Global Grid-Connected Stationary Battery Storage Capacity, by Country, 2006-2016

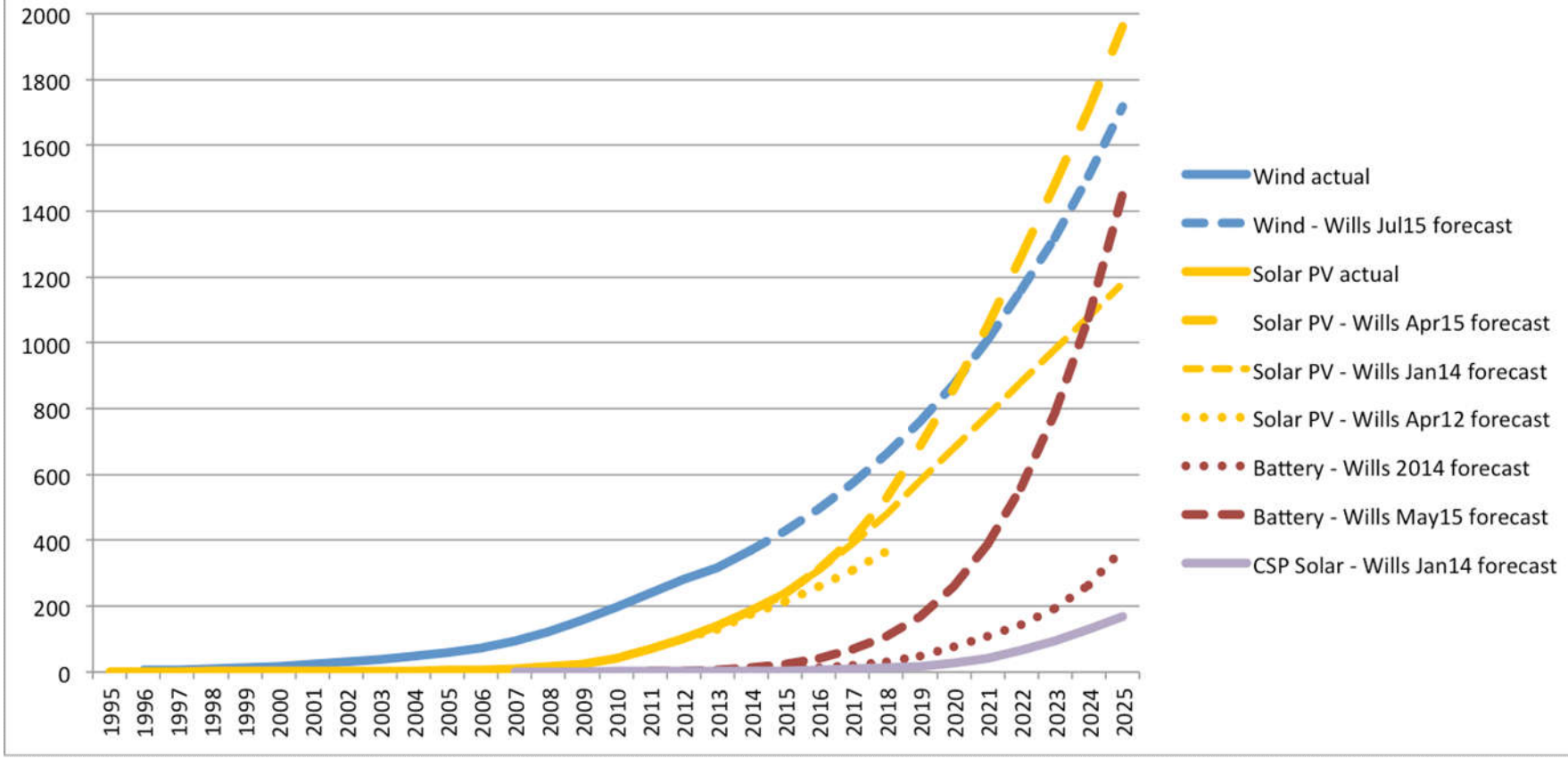


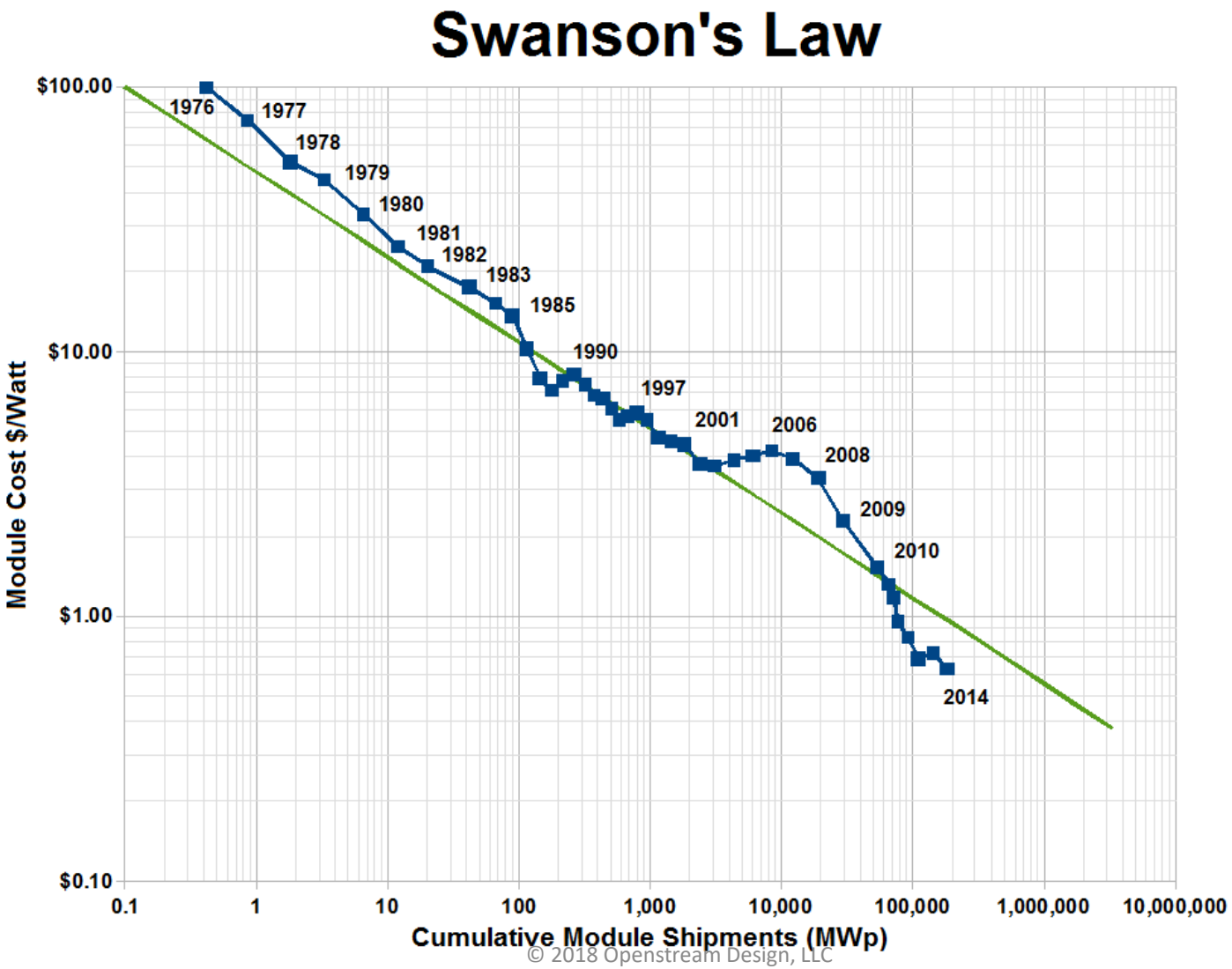
REN21 *Renewables 2017 Global Status Report*

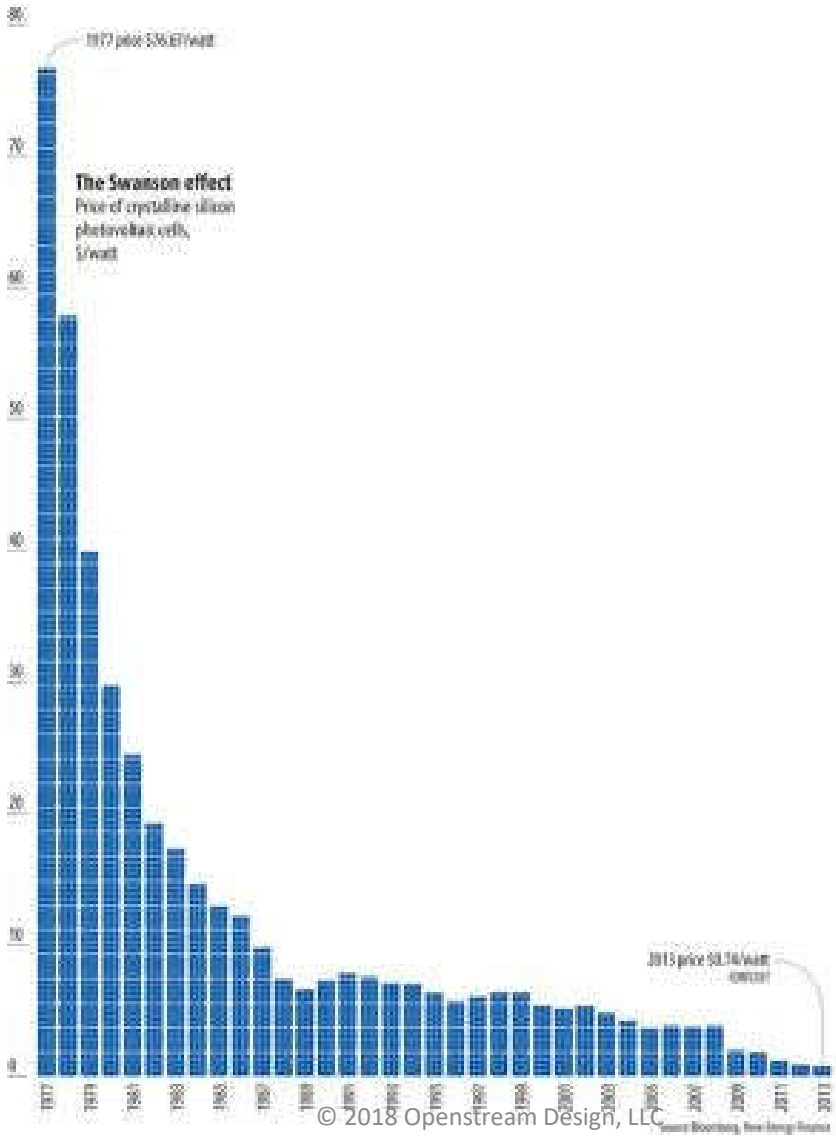


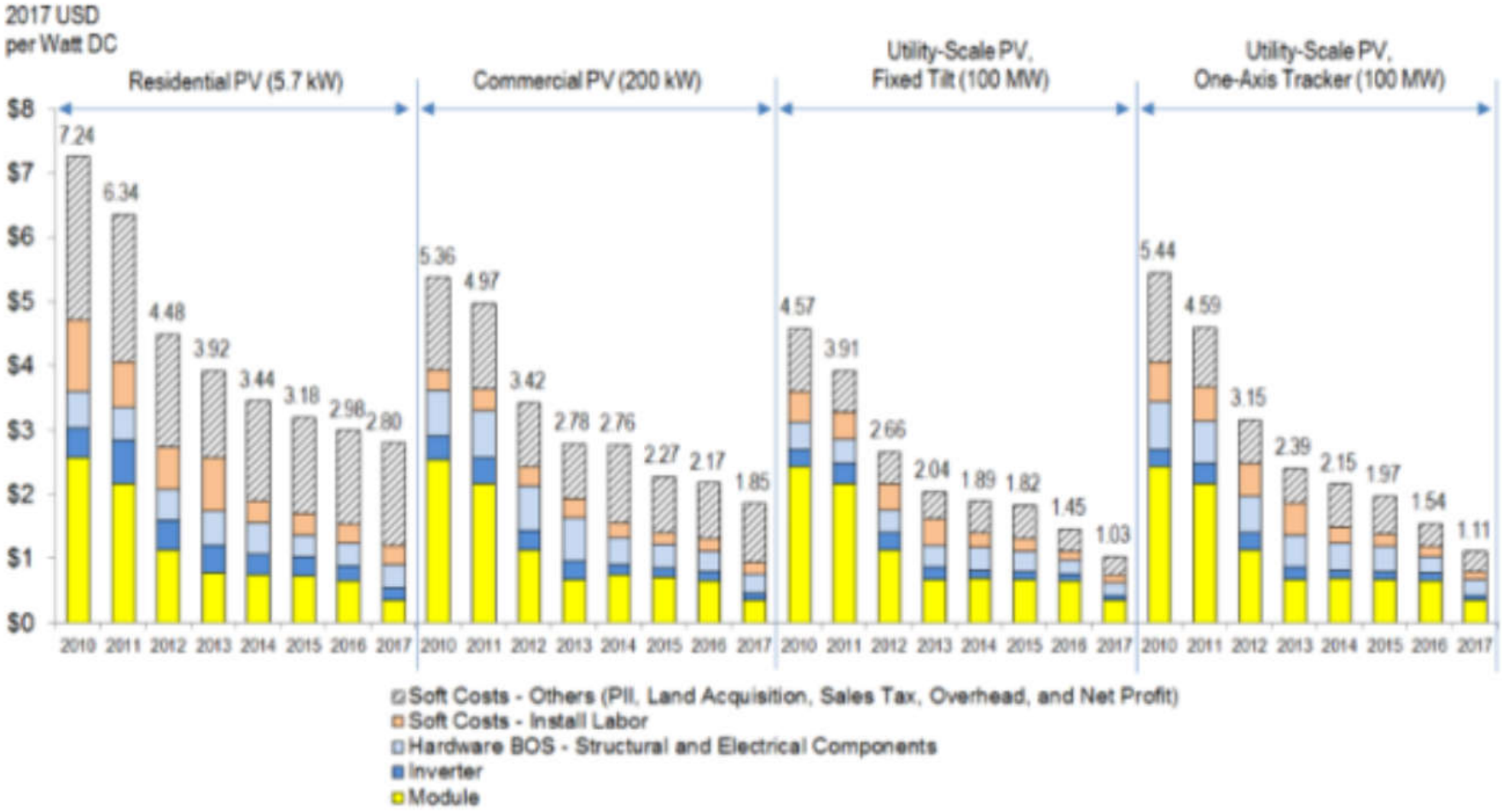
Global capacity growth 2014 and forecast to 2025

wind, PV, CSP (GW) battery (GWh) actual; forecast @ProfRayWills Data update 20Jul15

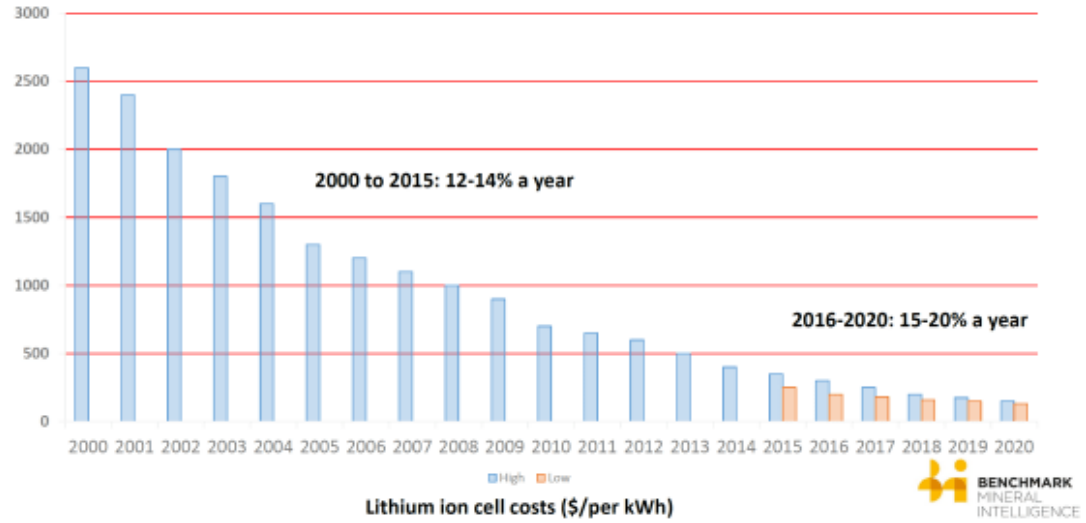




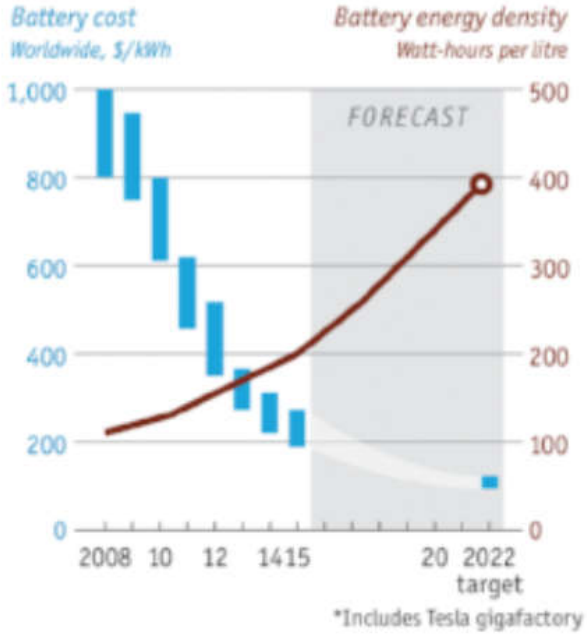




… and battery cell costs are falling

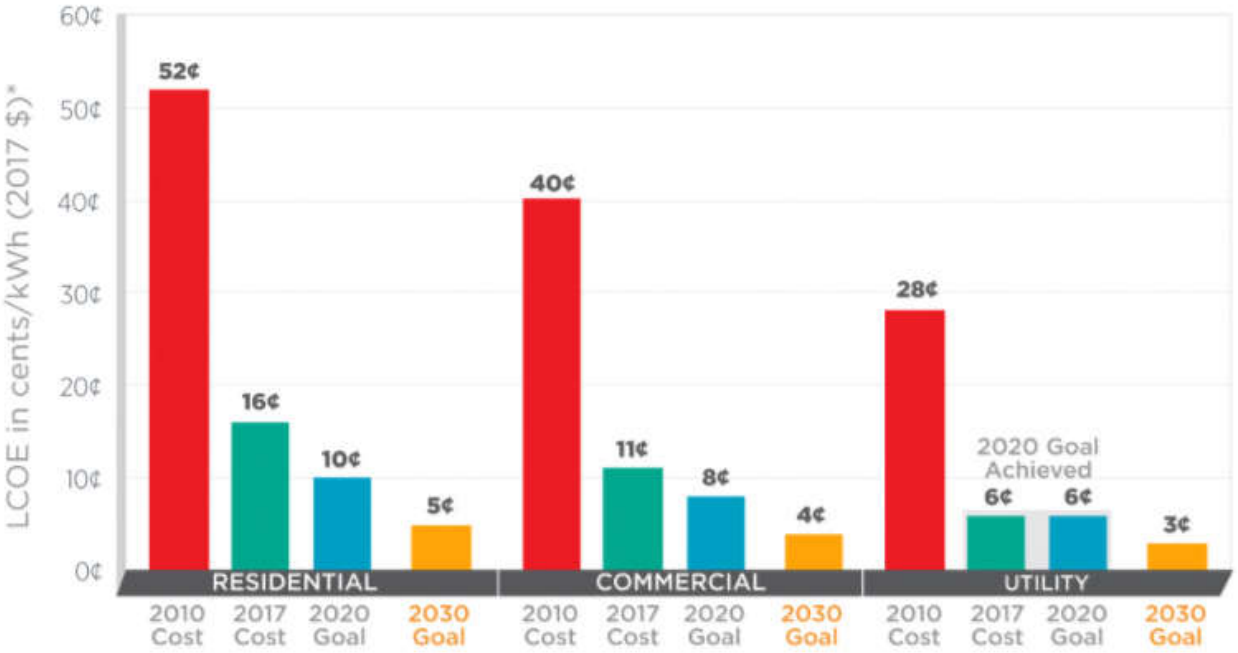


Lithium ion cell costs ($/per kWh)



SunShot
U.S. Department of Energy

SunShot Progress and Goals



*Levelized cost of electricity (LCOE) progress and targets are calculated based on average U.S. climate and without the ITC or state/local incentives. The residential and commercial goals have been adjusted for inflation from 2010–17.

“What happens when solar and batteries join forces?

Together they can make the electric grid optional for many customers—without compromising reliability and increasingly at prices cheaper than utility retail electricity.”

Storage media

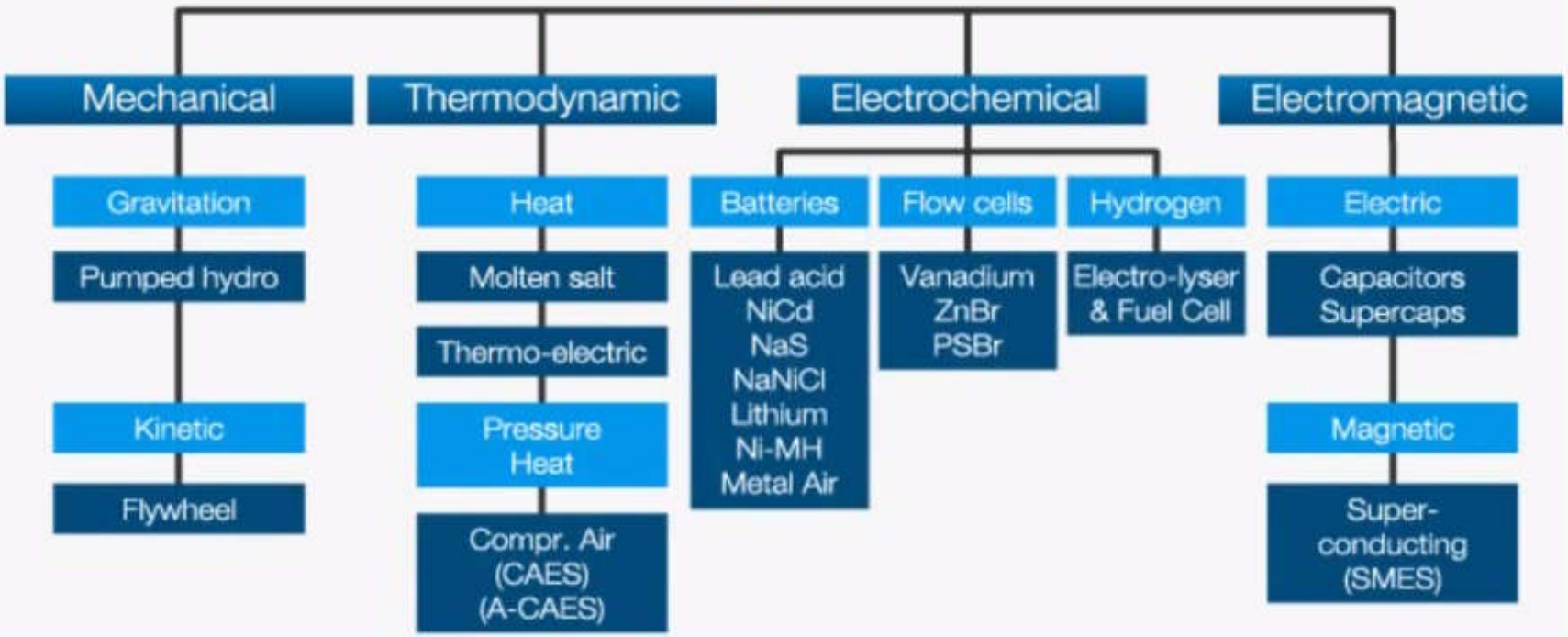
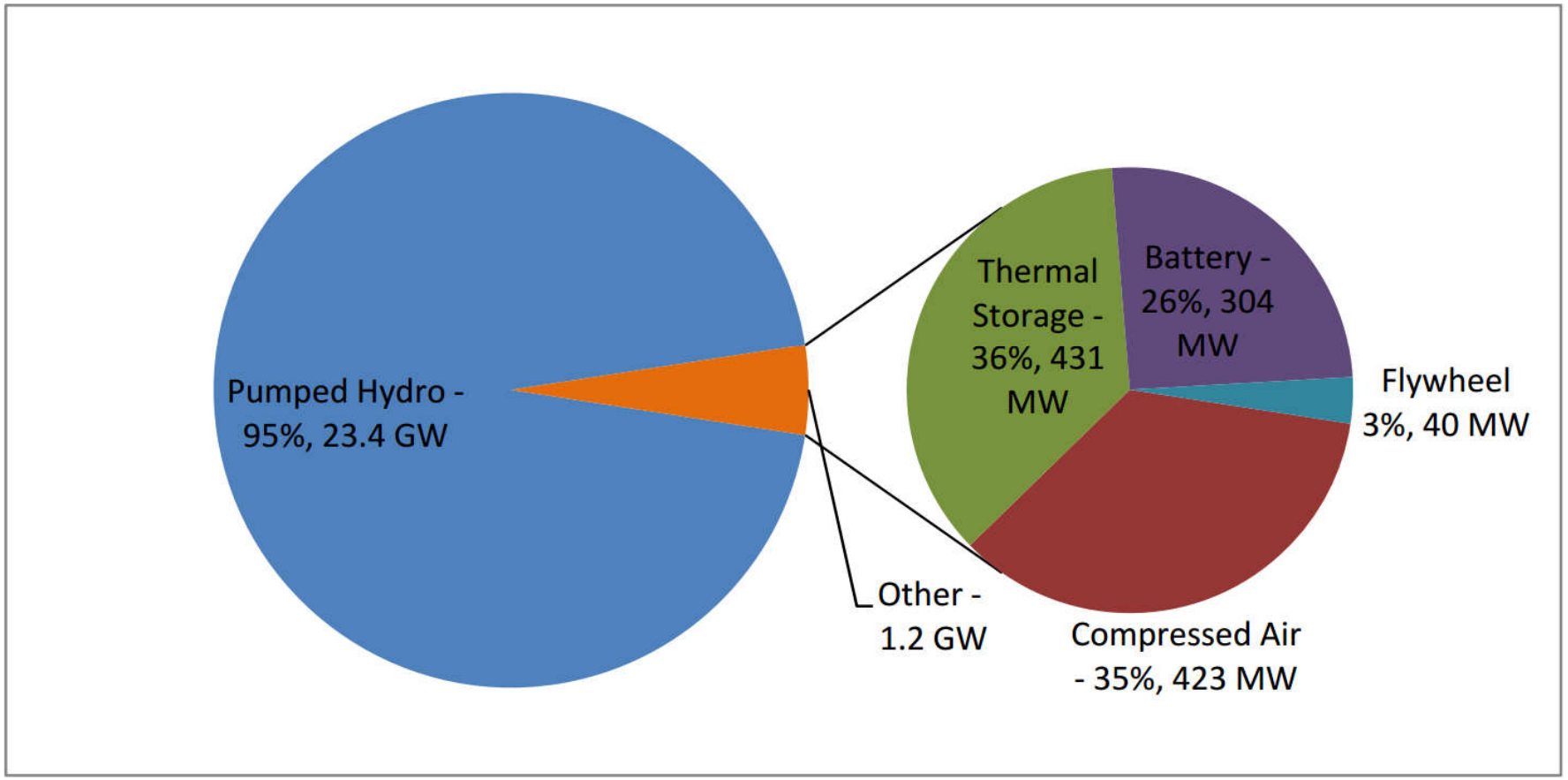
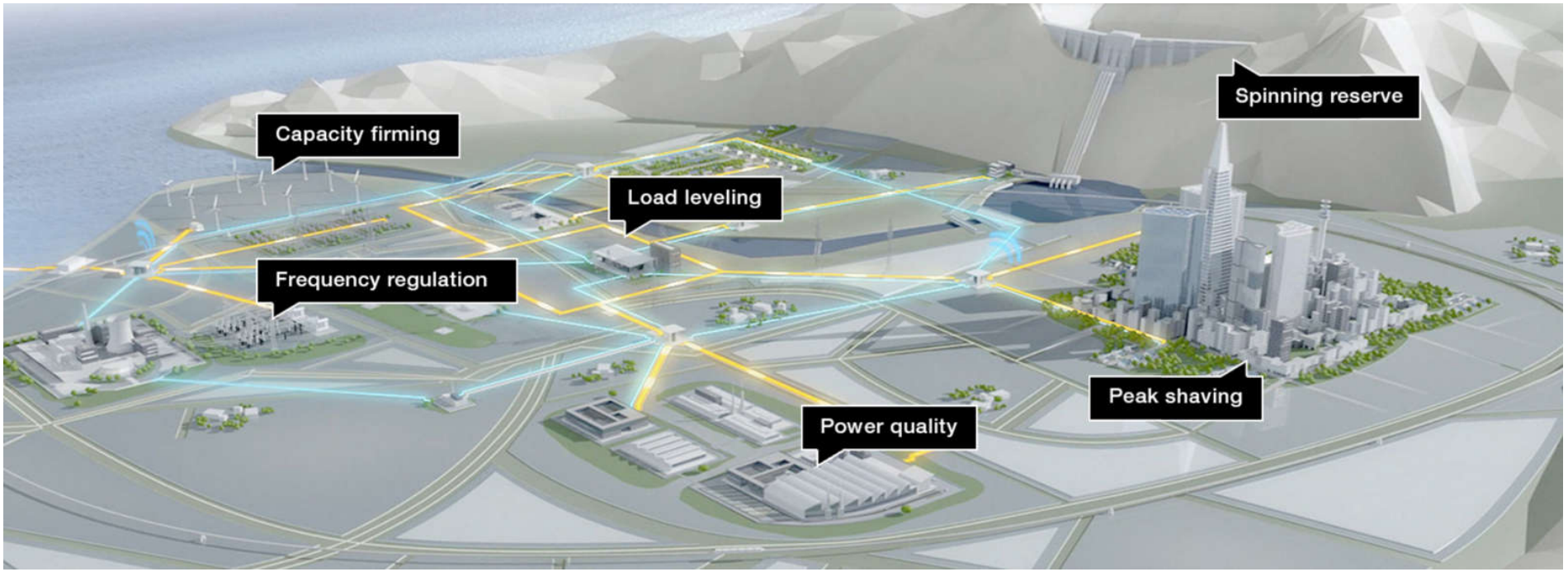


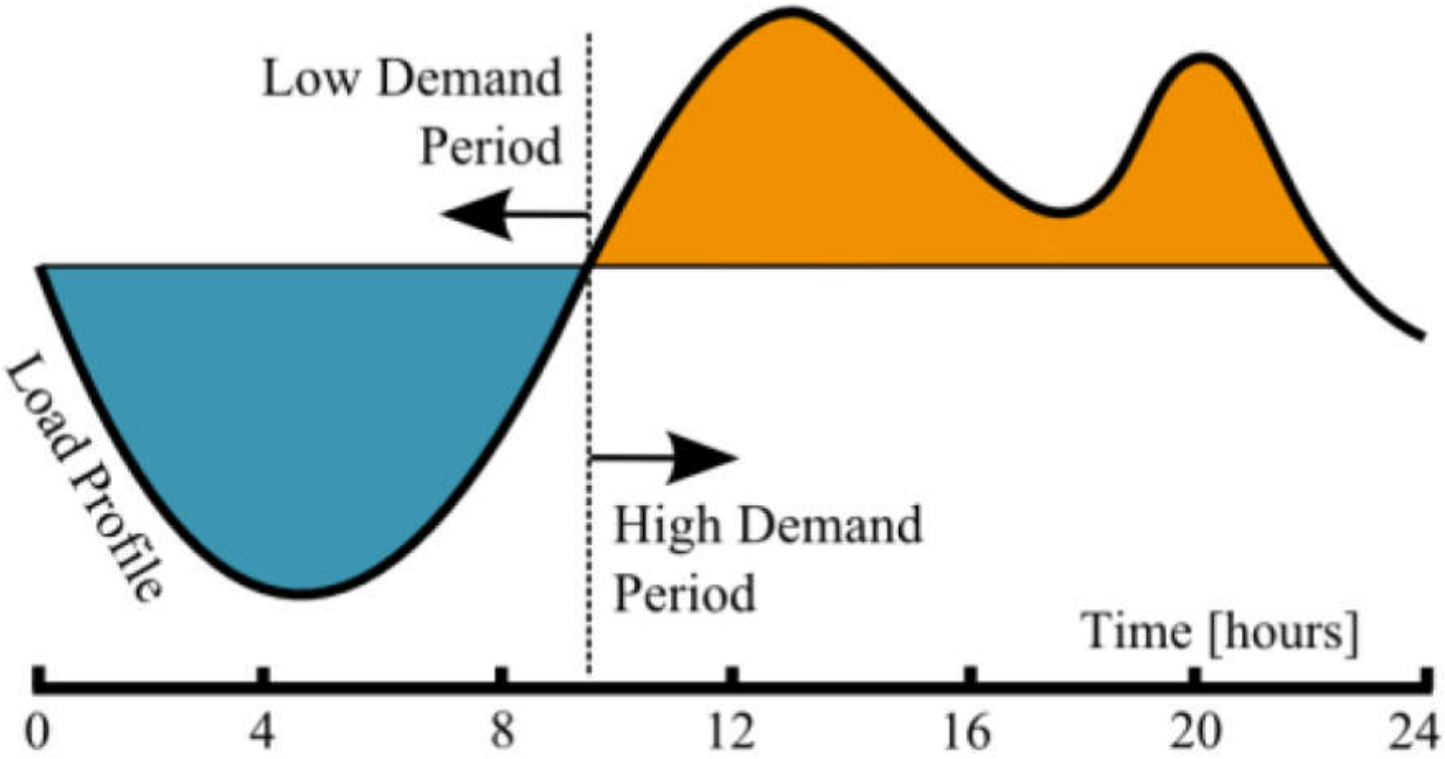
Figure 1 – Rated Power of US Grid Storage projects (includes announced projects)



The Smart Grid: storage from a generation perspective



Source: ABB Power and productivity for a better world™



The problem of curtailment

"reduction in the output of a generator from what it could otherwise produce given available resources"

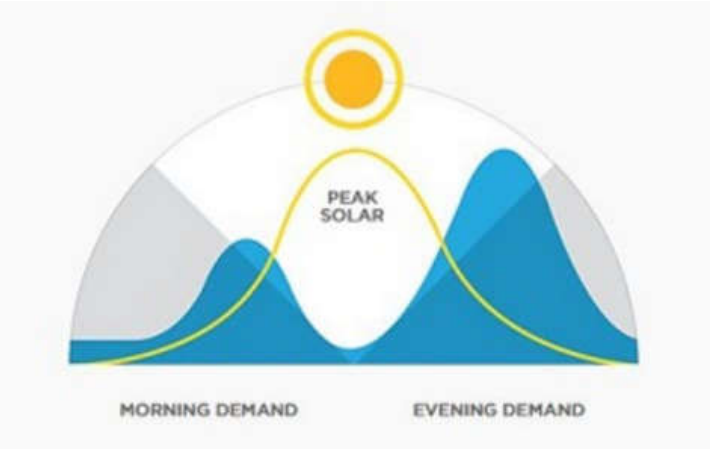
"During 2015, China installed some 33 gigawatts of wind turbines, which was more than half of new wind installations worldwide. But, in the same year, government statistics show "33.9 billion kilowatt-hours of wind-powered electricity was wasted … equivalent to the electricity consumed by 3 million American households a year,"

The end-user (demand-side): reasons for storage

UPS: Have power when there's a utility outage

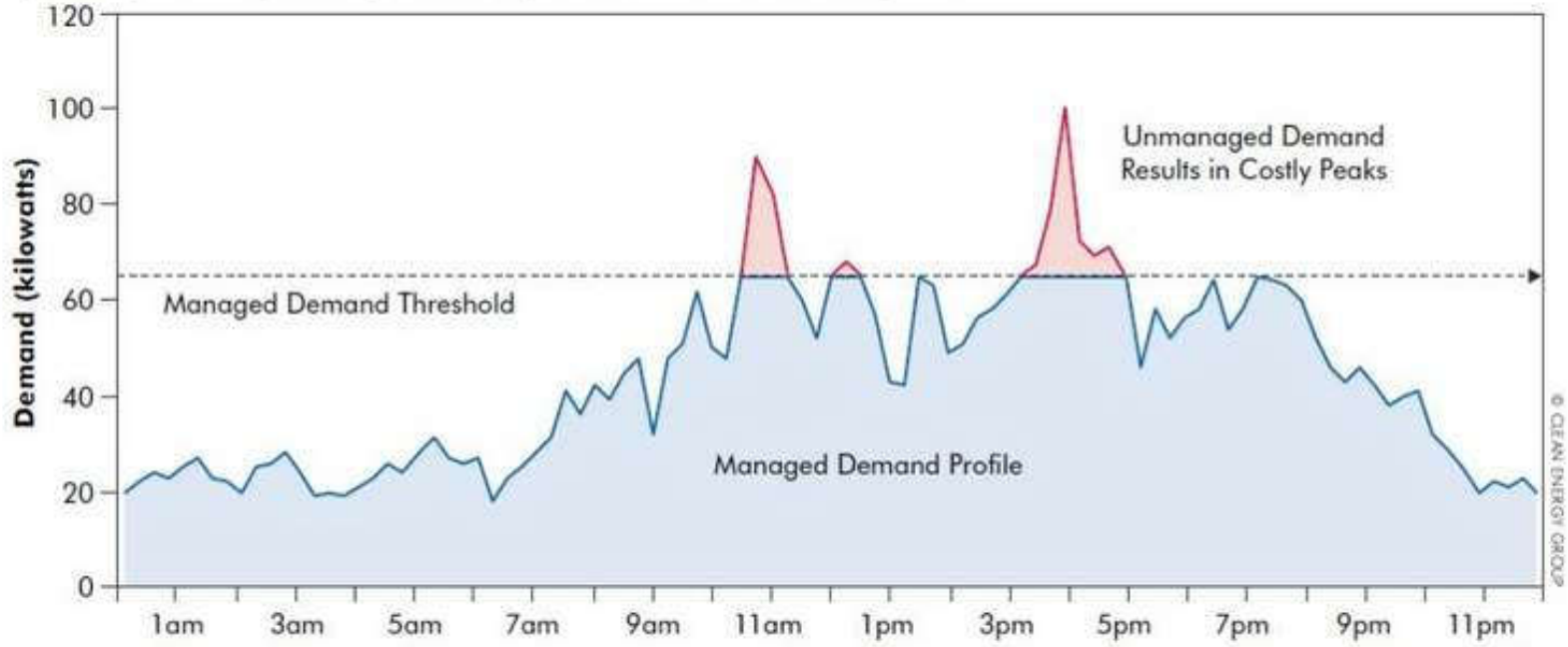
Peak Shifting/Time of Use: Taking advantage of shifting your solar power into times of greater usage (e.g. morning and late afternoon) for economic reasons

Grid-defection: Going net-zero - getting off the grid for personal or environmental reasons

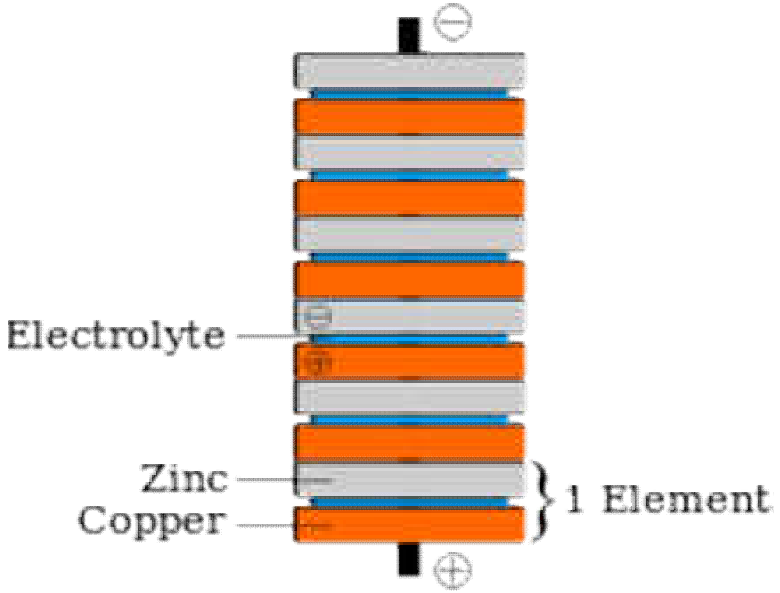


The problem of unmanaged demand

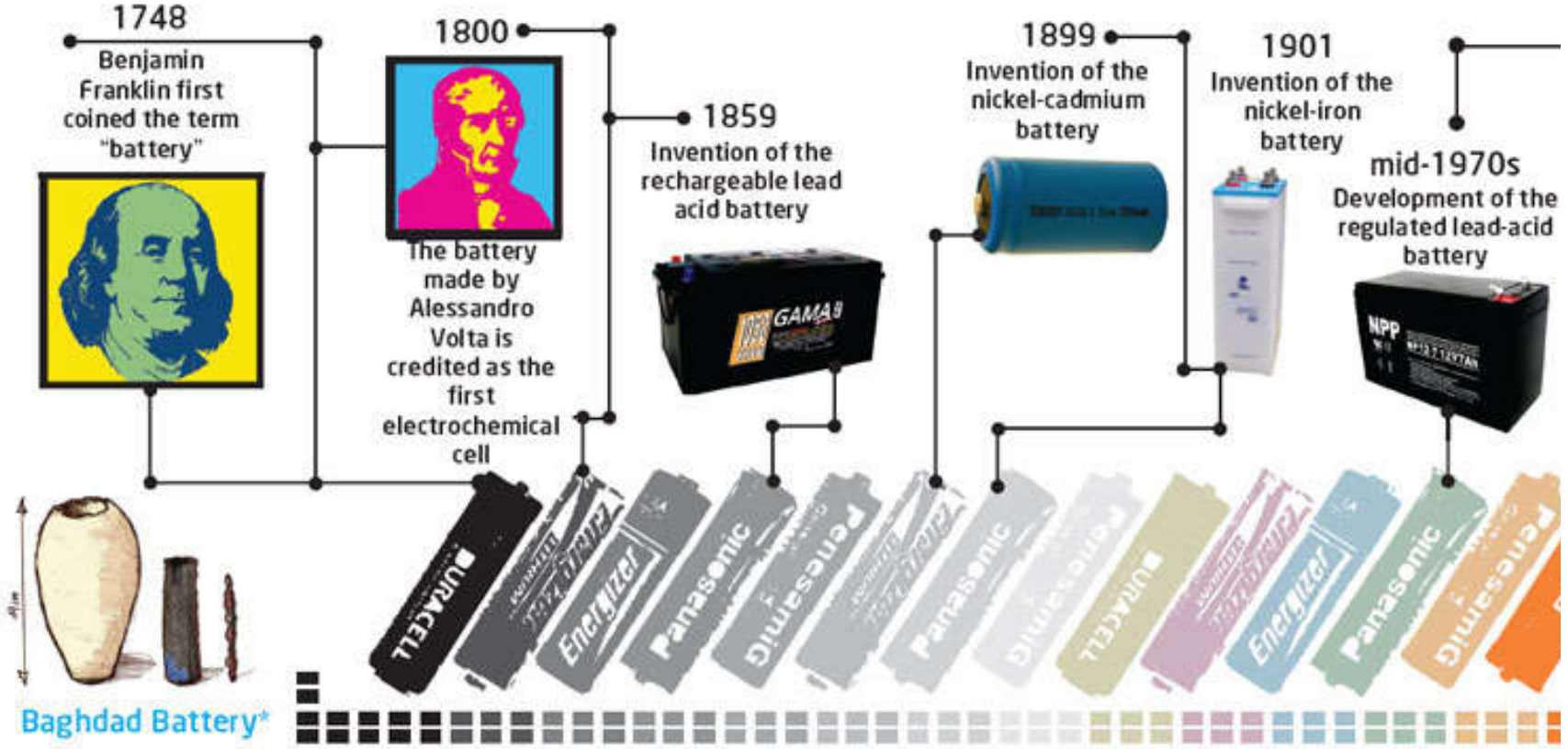
How battery storage can help manage electricity demand over a 24-hour period



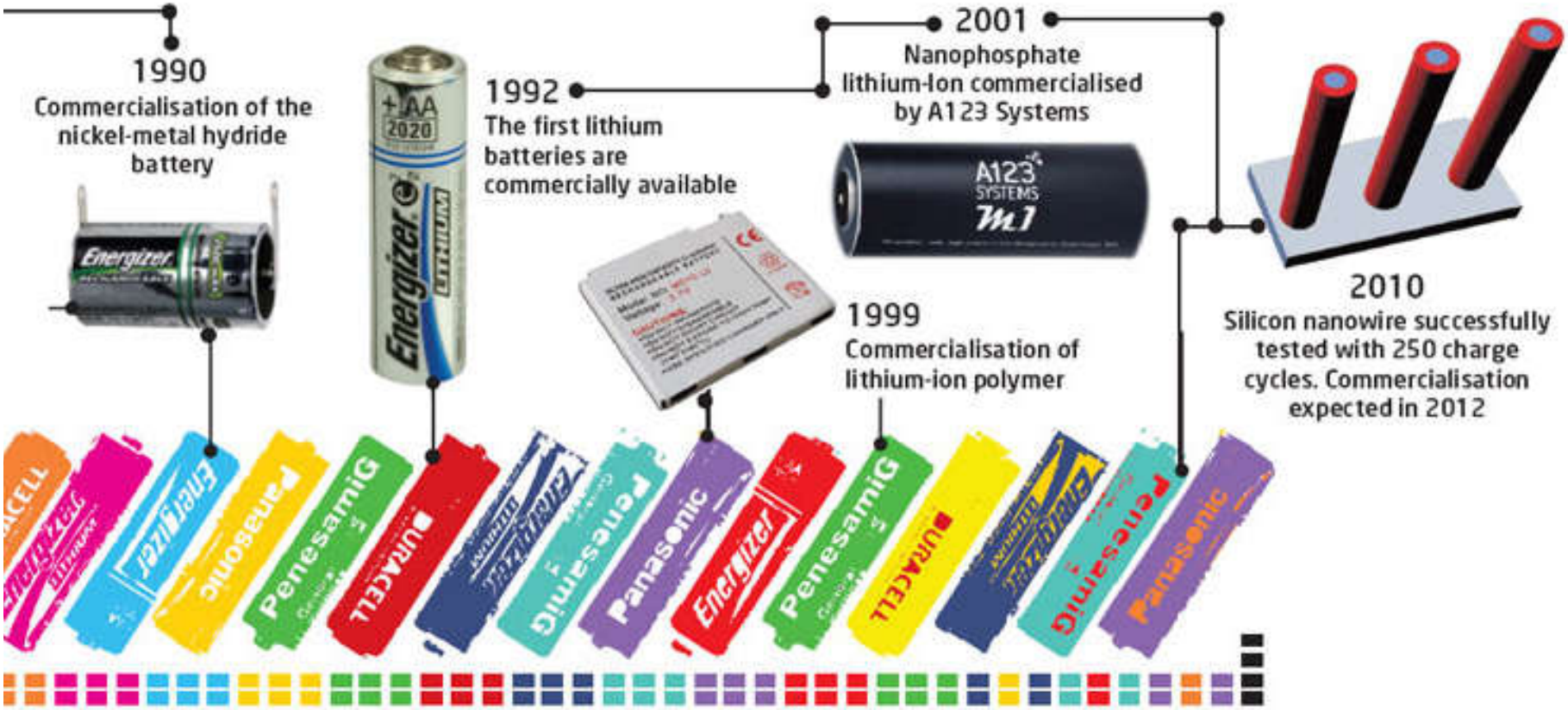
Through the deployment of an energy storage system, peak demand can be effectively capped at a specified level—significantly reducing utility demand charges. Assuming a demand charge of $10 per kilowatt and peak demand reduction from 100 kilowatts to 65 kilowatts each period (as shown here), energy storage could reduce the customer's demand charge by $350 per billing period, amounting to an annual savings of $4,200.

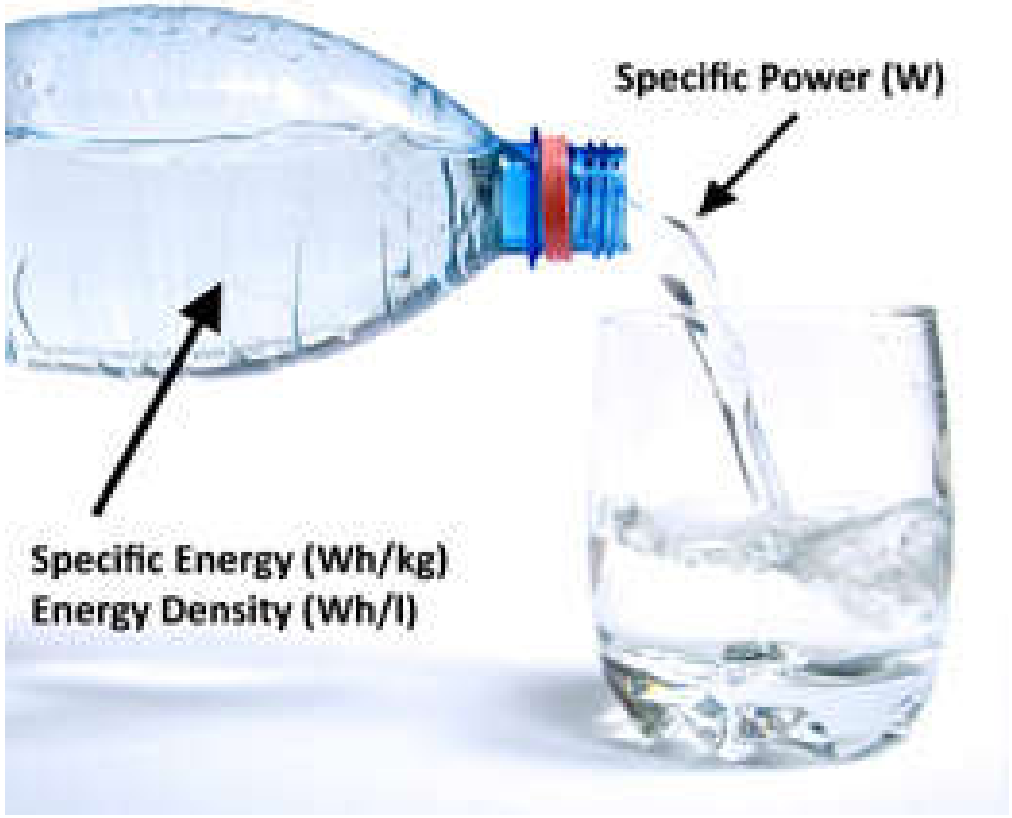


HISTORY OF THE BATTERY



*There is a possibility that the battery was invented twice. Discovered by German archaeologist Wilhelm Konig on the outskirts of Baghdad, terracotta jars with a copper sheet inlay and an iron rod. These two combine to form an electrochemical couple in an electrolyte, the building blocks of a battery. The jars are believed to be 2000 years old.





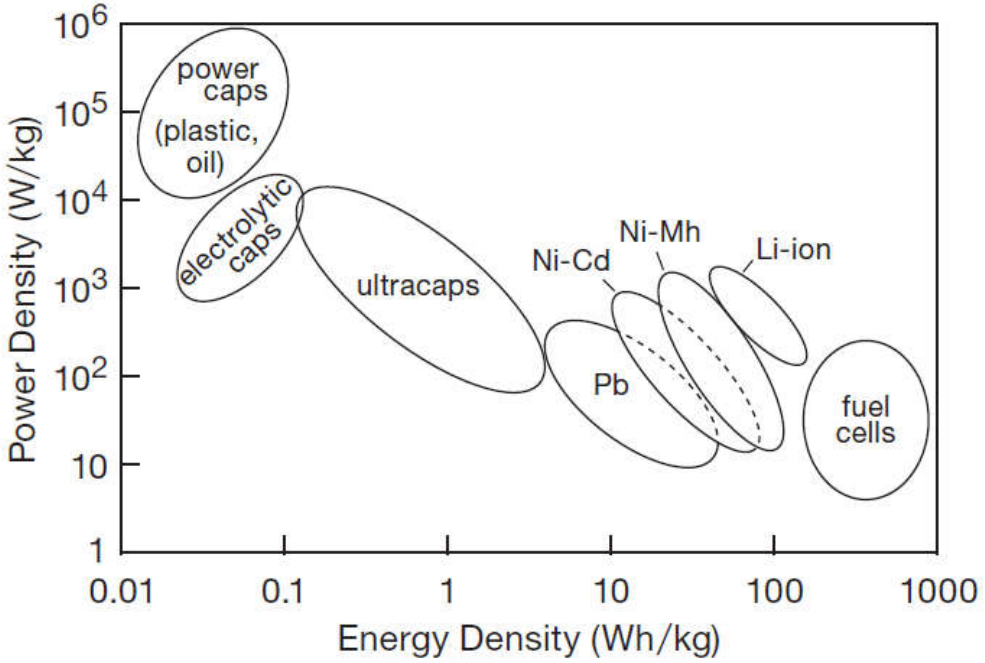


Figure 9.101. Energy-storage capacitors excel in delivering peak power, but batteries win out in energy storage, as seen in this "Ragone plot."

Lead-Acid

- Been around for 100+ years and so is “well-understood”
- Easiest to use
- Still life in them with newer “advanced” lead-acid with carbon-infused negative plate
- Full charge controllers support

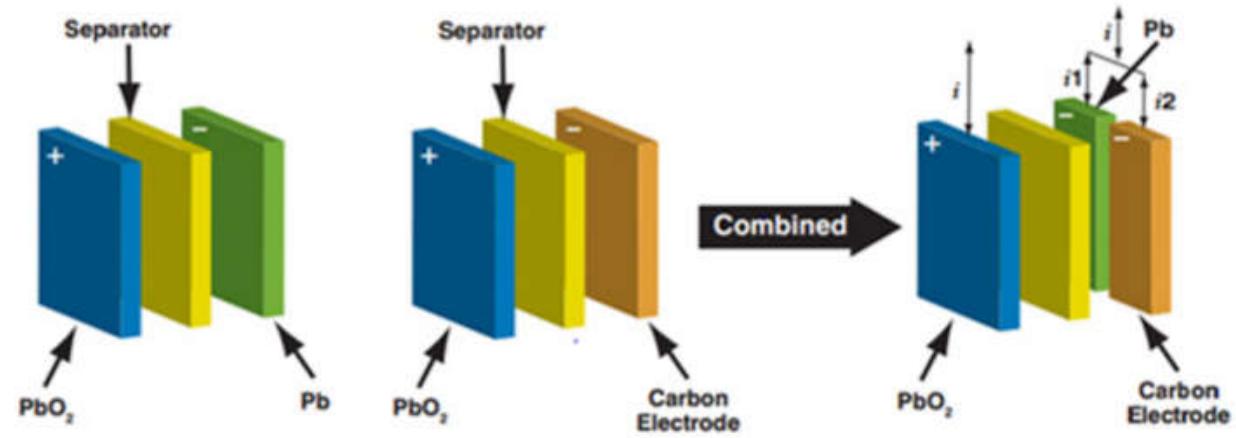
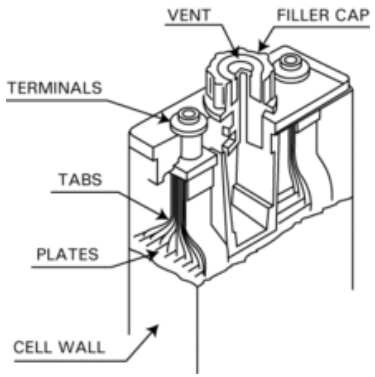


Figure 1: The classic lead acid develops into an advanced lead-carbon battery. The negative plate is replaced with a carbon electrode that shares the qualities of a supercapacitor.

Courtesy of Advanced Lead-Acid Battery Consortium (ALABC)

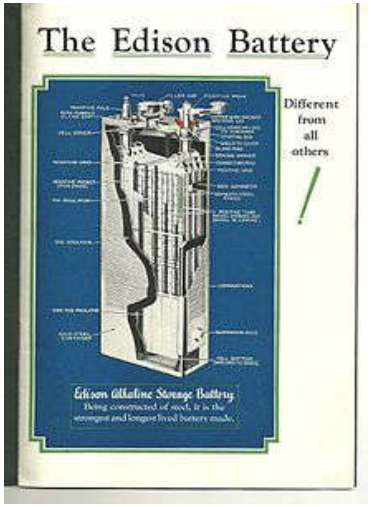
Nickel: Ni-Cad

- Also been around for 100+ years and so is “well-understood”
- Vented flooded (wet) cells are used for large capacities
- Very common in aviation, rail, mass-transit, backup power for telecom, and engine starting for backup turbines.
- Requires maintenance every few months
- Tolerates deep discharges
- Can suffer from a “memory” effect
- Cost effective

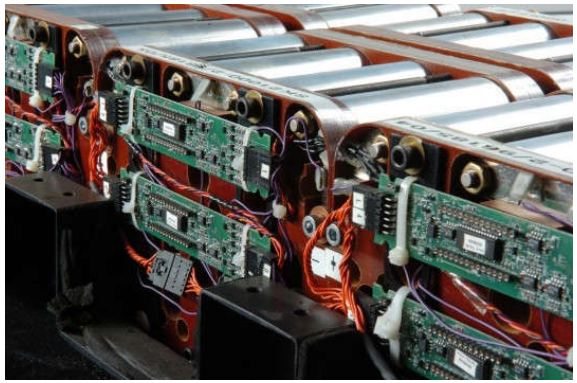


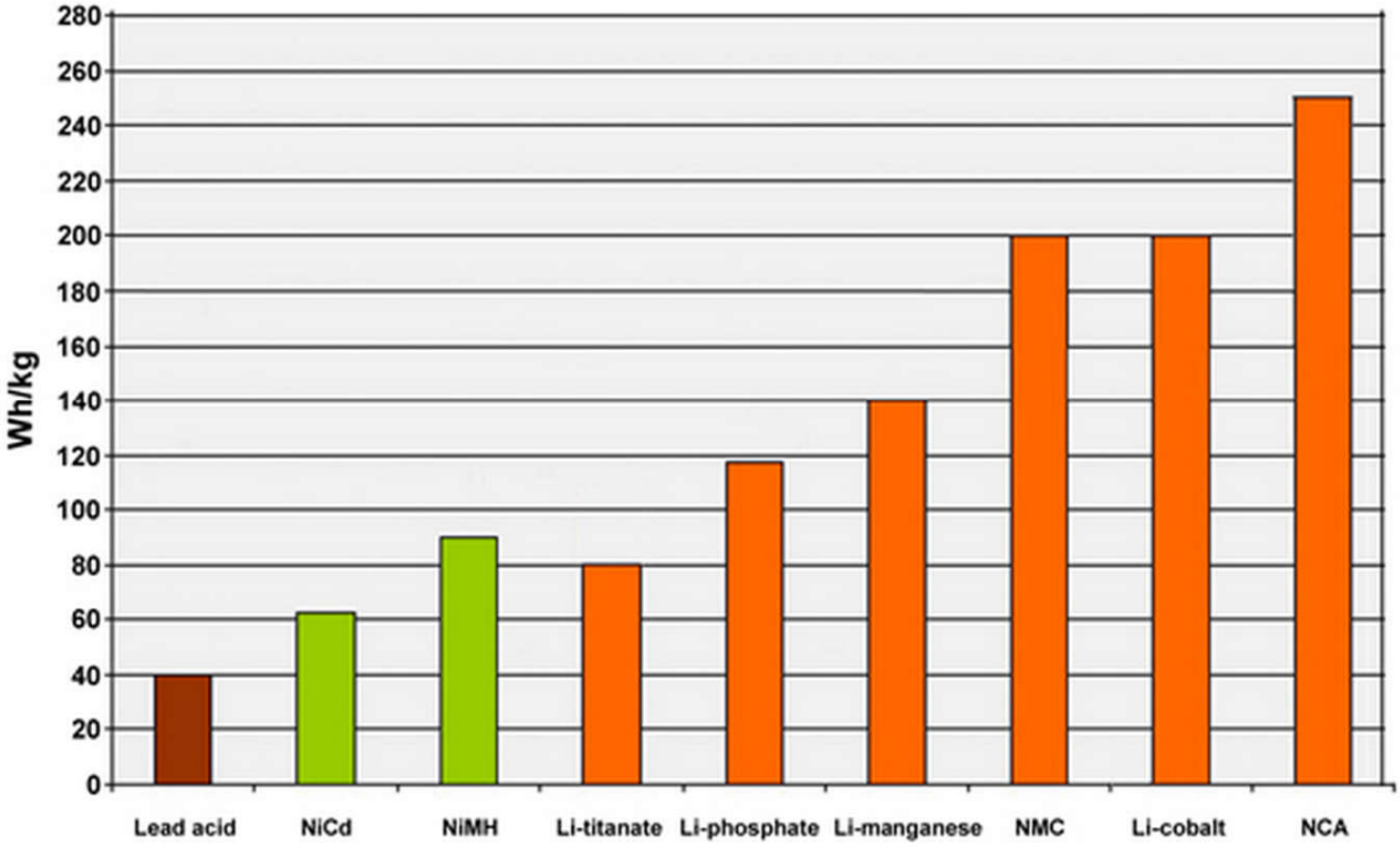
Nickel: Nickel-Iron (NiFe)

- Also been around for 100+ years but went out of favor for a long time
- Used mainly in European mining operations because of their ability to withstand vibration, high temperatures, and other physical stress. Also used in railway vehicles.
- Very common in aviation, rail, mass-transit, backup power for telecom, and engine starting for backup turbines.
- Very long life (in backup situations for more than 20 years if charged continuously)
- Traditionally it has had low specific energy, poor charge retention, and high cost of manufacture.
- However, the slow charge and discharge has been sped up 1000-fold by use of graphene and carbon.
- Iron-Edison has 500Ah (1.2Vdc) batteries. Energy density is improving.

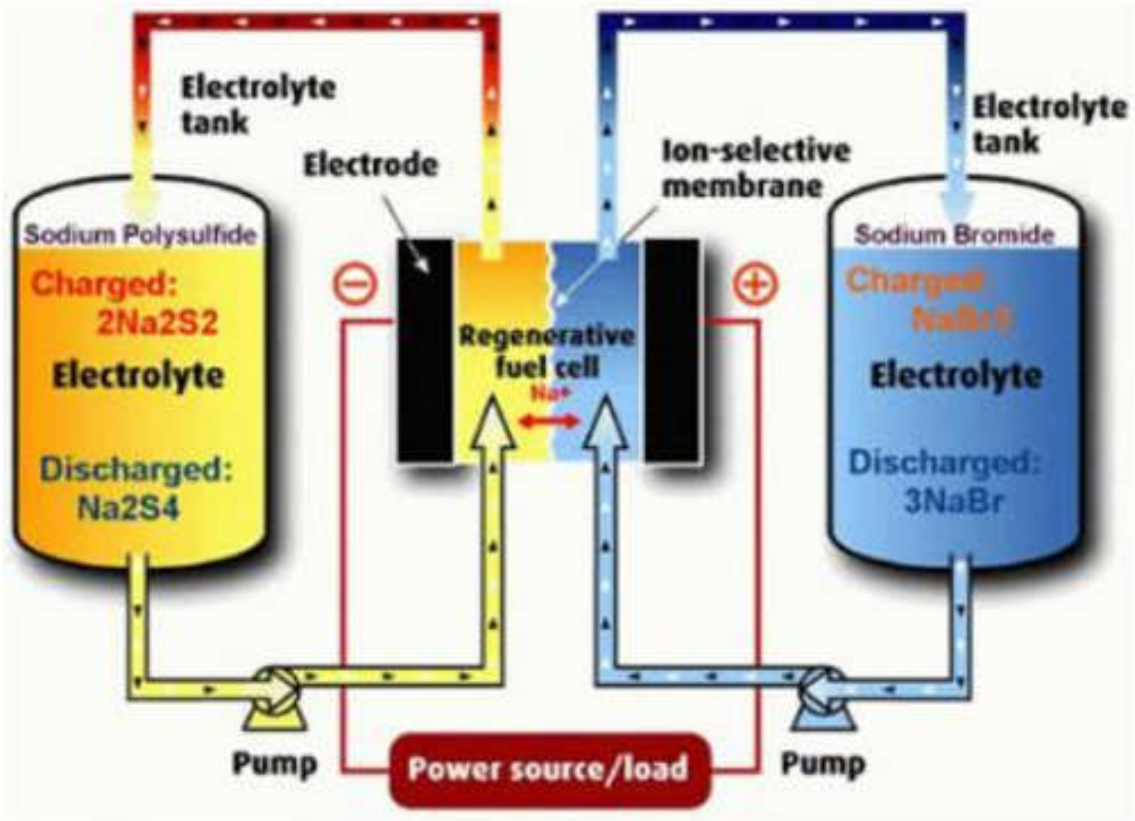


Lithium-Ion Family





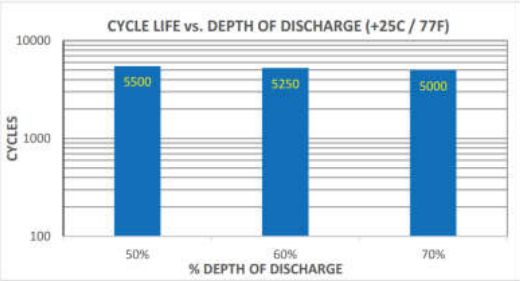
Flow Battery

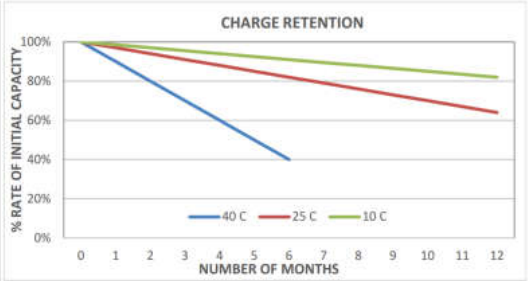


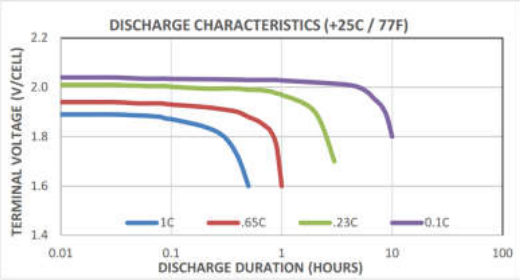
Spec sheets are typically 2-pages with the cover page promoting the benefits of the battery/cell

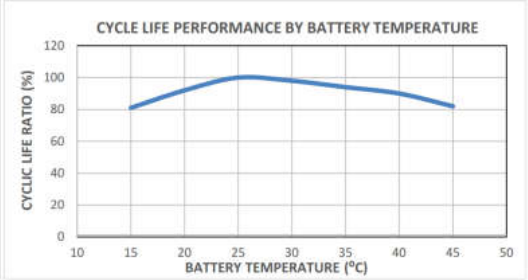
GS ECO R

ADVANCED LEAD DEEP CYCLE BATTERY
SLR1000-2



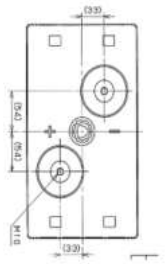


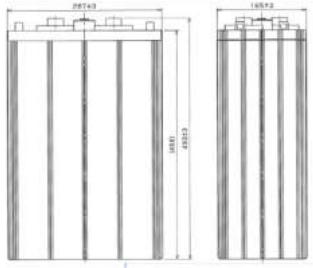




Battery Characteristics			
Terminal Type	Battery Type	Battery Capacity (10 HR)	Battery Voltage
Bolt (M8)	Advanced VRLA AGM	1000Ah	2 Volts

Physical Characteristics (±3mm)						
	Length	Width	Case Height	Overall Height		Weight
Inches	11.30	6.50	18.43	19.41	Pounds	147.71
mm	287	165	468	493	kg	67





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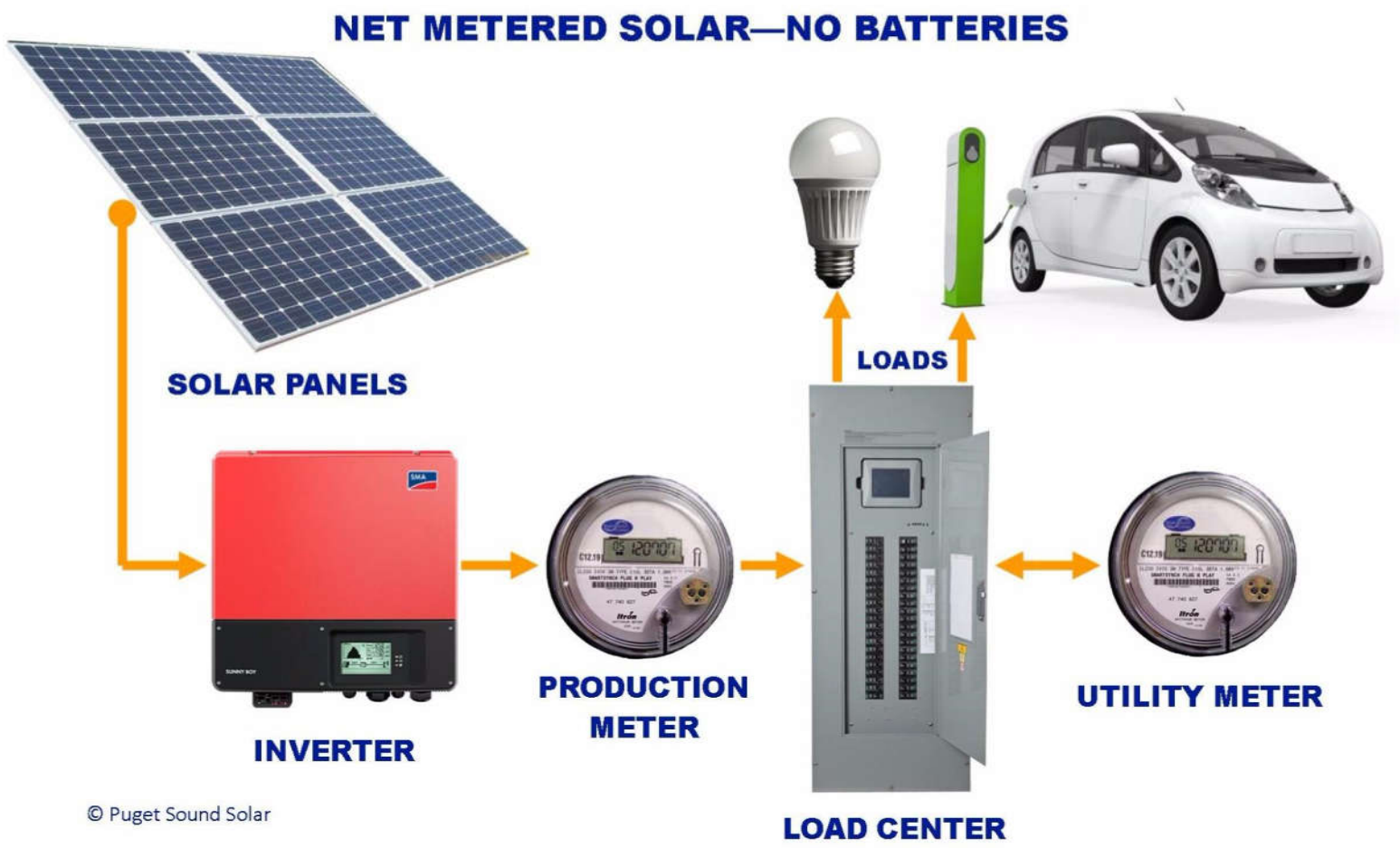
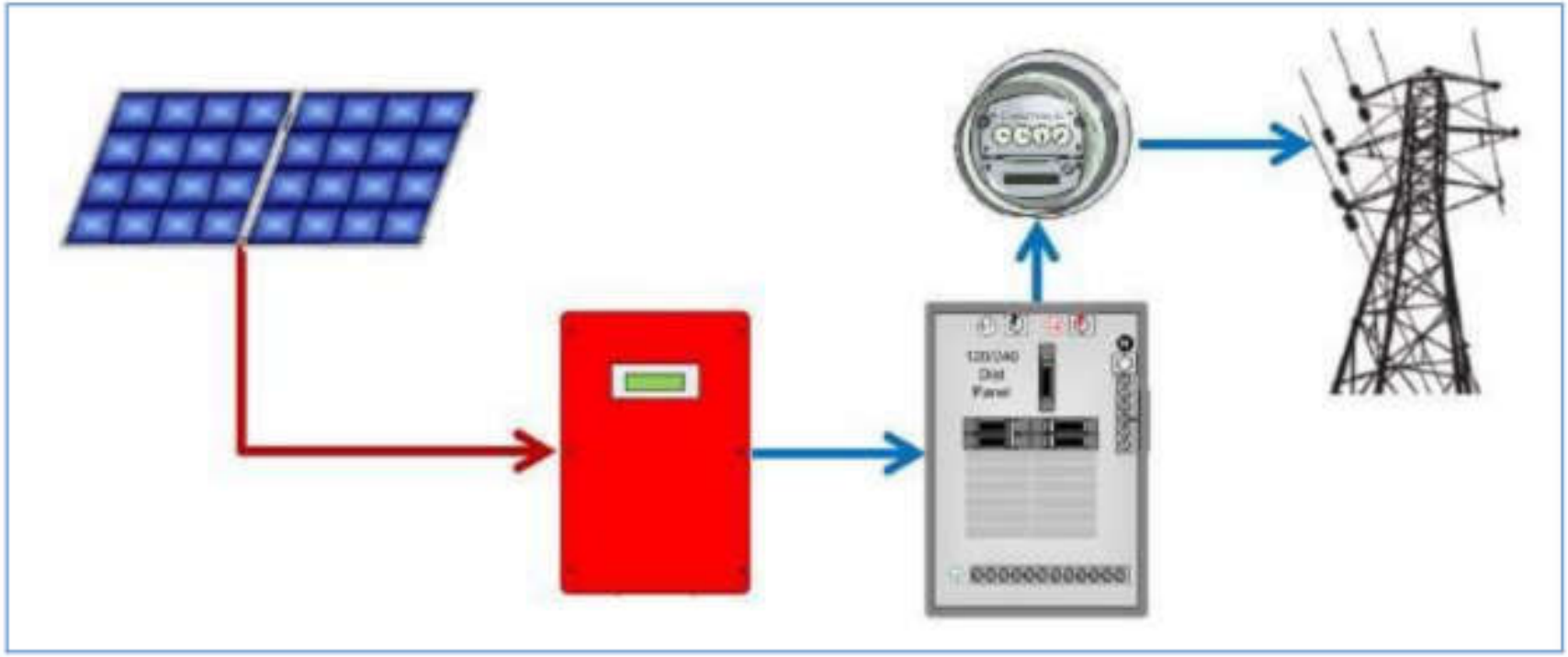
Second page provides the electrical and mechanical characteristics



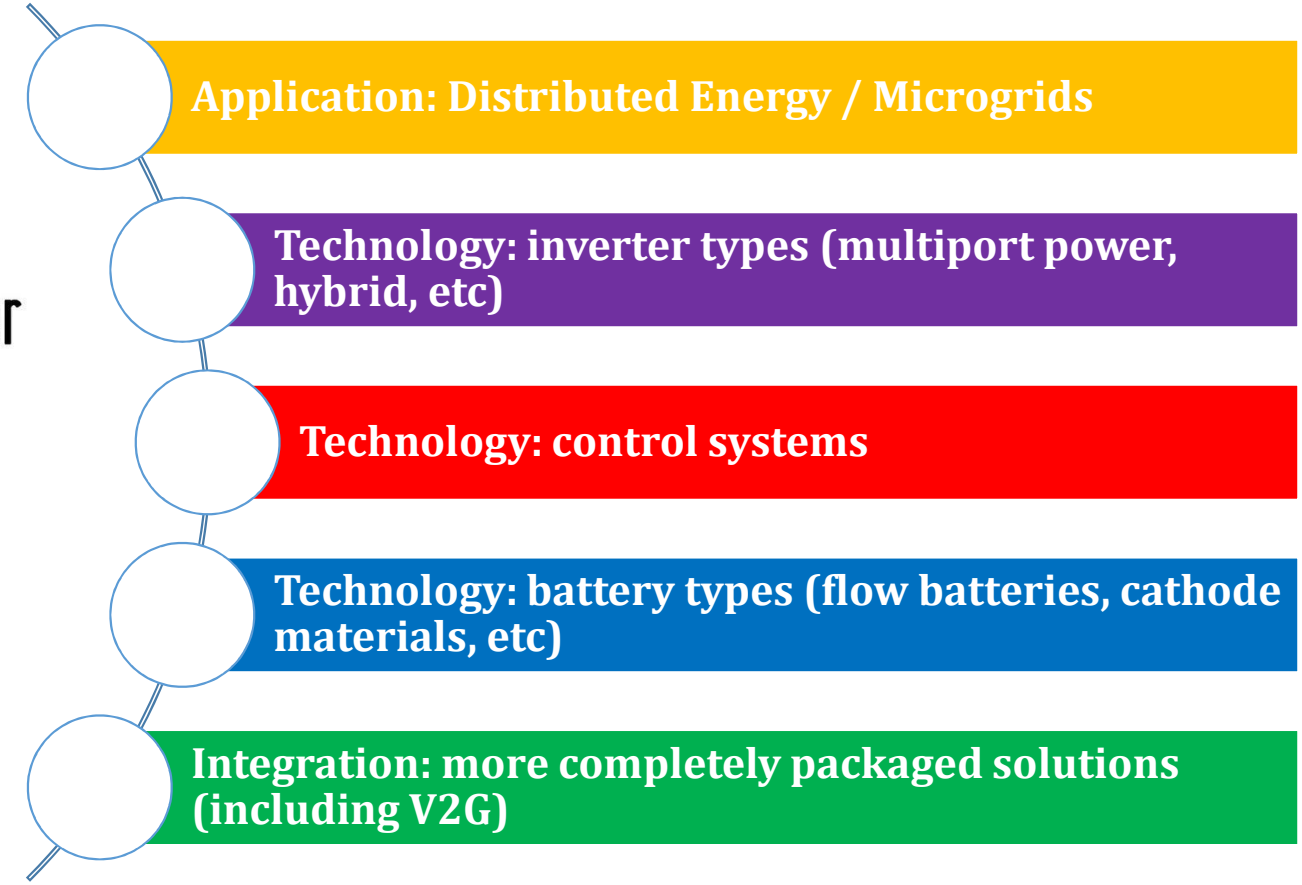
Standard Grid-Tie system



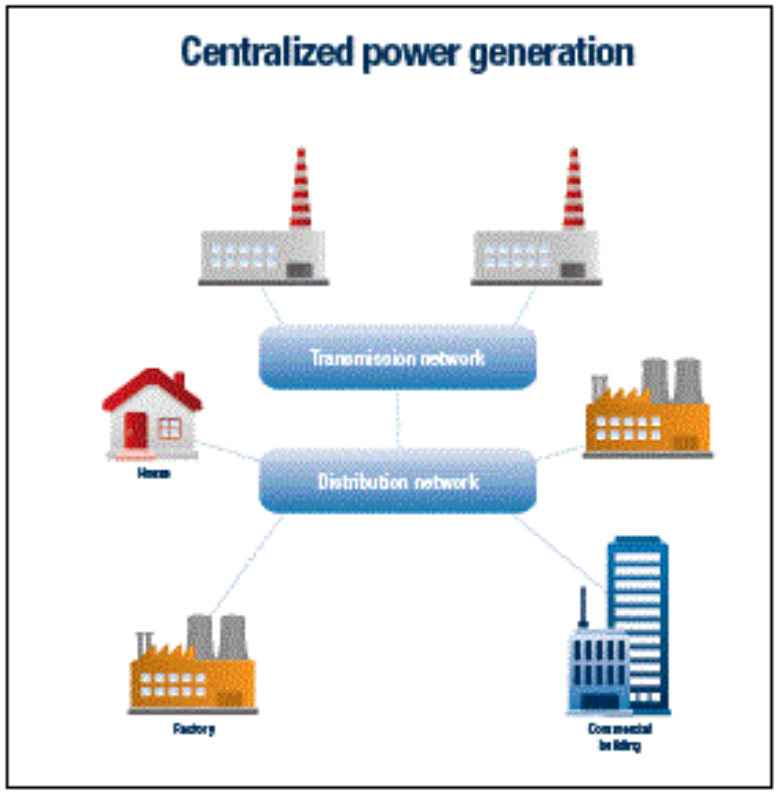
Sizing up a system with:

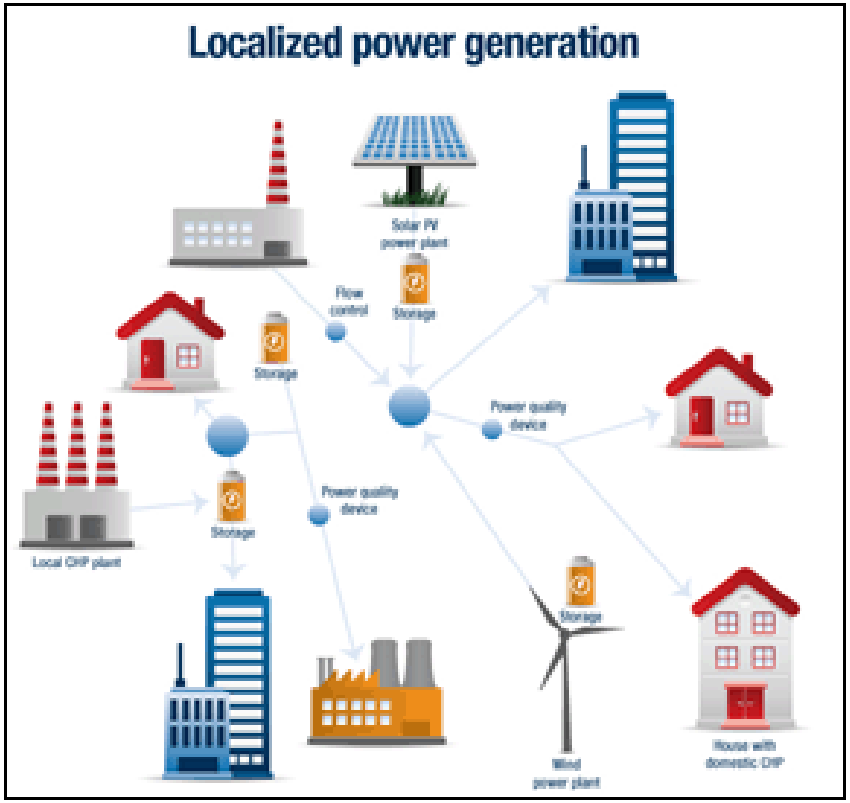
https://solarresilient.org/

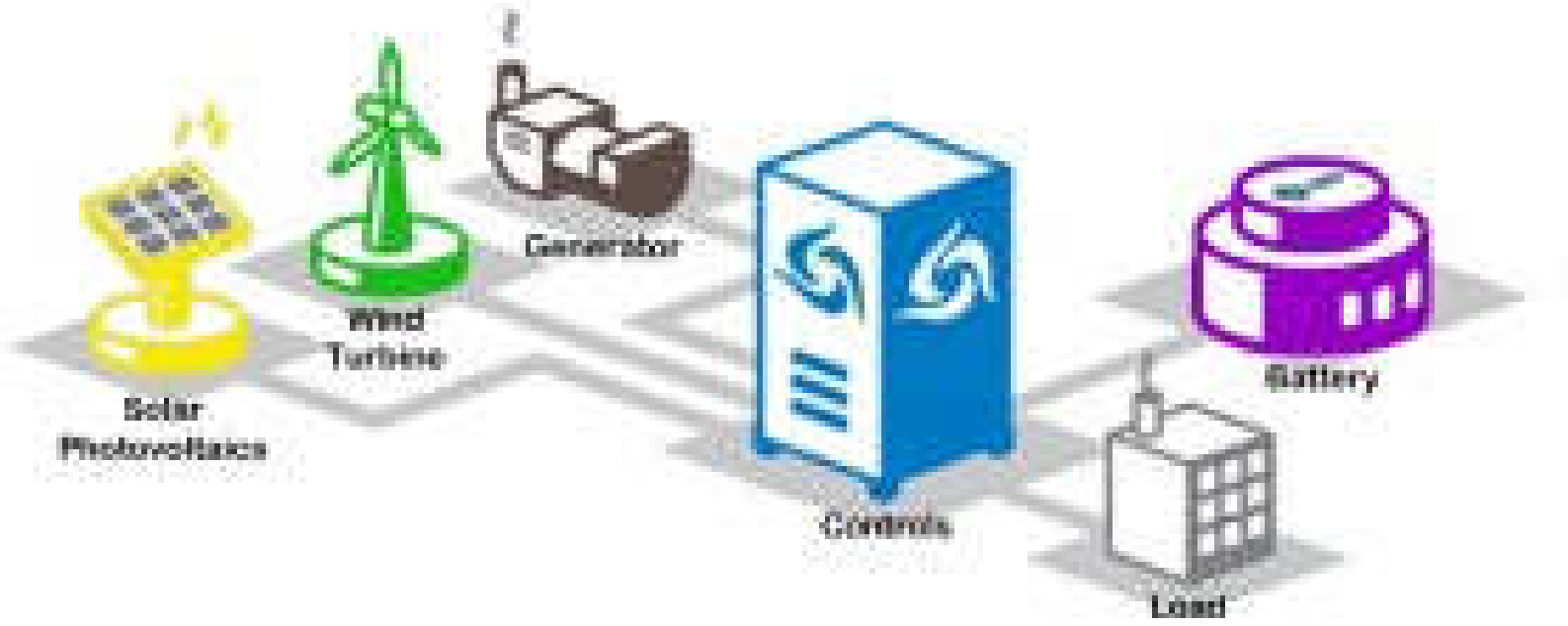
With great power comes great electricity bill.



DISTRIBUTED ENERGY



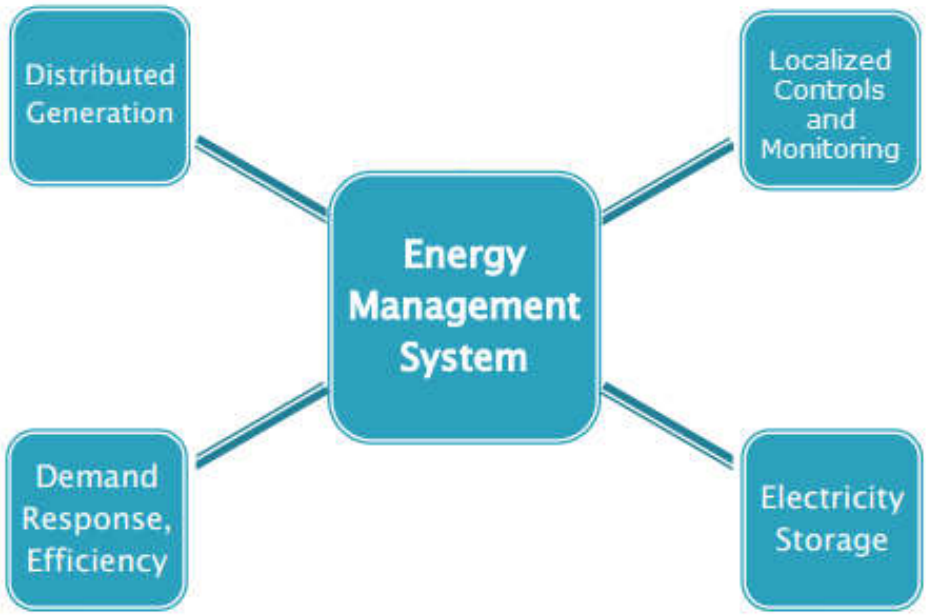


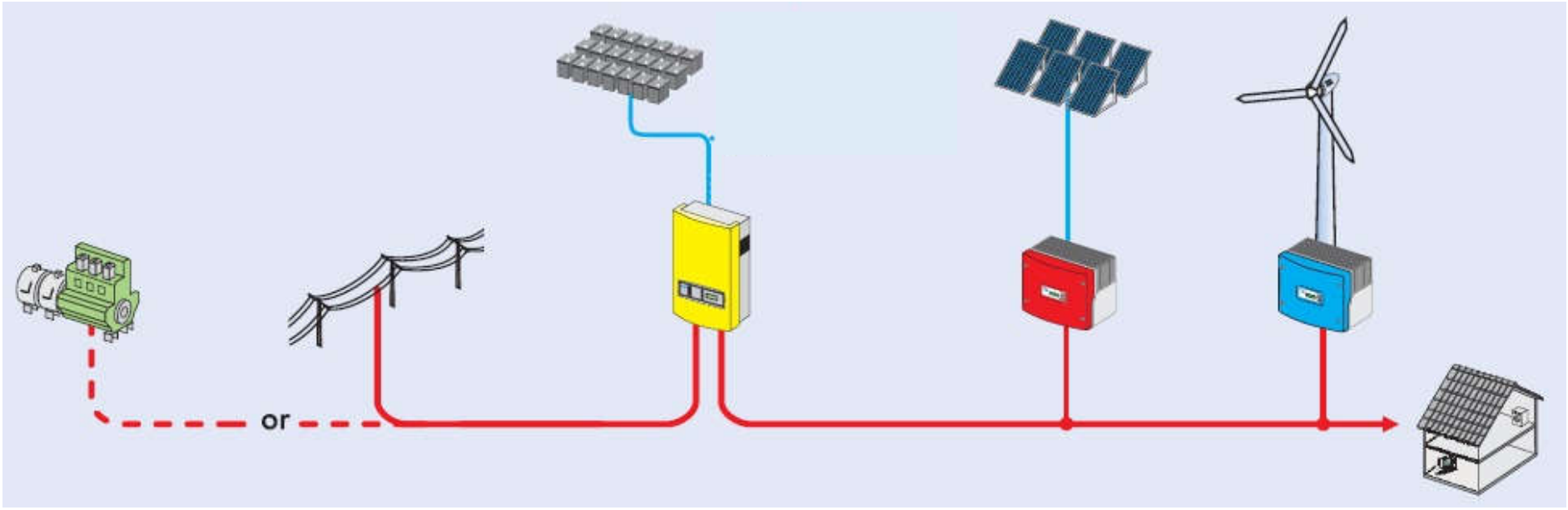


Microgrids

A microgrid is a small-scale power grid that can operate independently or in conjunction with the area's main electrical grid. Any small-scale localized station with its own power resources, generation and loads and definable boundaries qualifies as a microgrid.

"A local energy system capable of balancing captive supply and demand resources to maintain a stable service within a defined boundary"
-Microgrid Institute
-http://www.microgridinstitute.org/





A 3-phase Microgrid System

BMZ
THE INNOVATION GROUP

ENERGY STORAGE SYSTEM 7.0

Premium Model

NEW!
Efficient Li-Ion storage system from the German storage expert!
Quality made in Germany at an outstanding price / performance ratio.

Now scalable to 6 units/40.44kWh

ENERGY STORAGE SYSTEM ESS 7.0

- Ideal for home and small business use
- Plug & Play installation
- 10 year/5,000 cycle pro-rated warranty
- Up to a 20 year lifespan
- High cycle stability
- Extremely compact design
- 8,000 watts continuous power

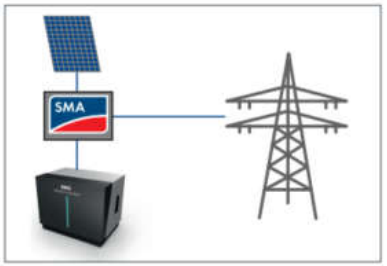
made in **GERMANY**
BMZ approved quality

SMA CERTIFIED

ESS 7.0 - Premium model

THE HIGHLY EFFICIENT STORAGE DEVICE FOR RENEWABLE ENERGY

- Environmentally friendly Lithium-Ion battery technology
- Up to a 20 year life
- Cycle stability at high current
- Arbitrary part cycling conditioning – no memory effect
- Fast charging: within one hour
- Efficient operation with active temperature control
- Safety approved technology – latest standards
- Integrated battery monitoring
- Integrated multilevel safety concept
  - Deep discharge protection
  - Voltage and temperature monitoring
  - Single cell monitoring (passive balancing)
  - State of charge determination
  - (SOC and SOH)
- Developed according to VDE-AR-E-2510-2, VDE-AR-E 2510-50, DIN EN 62619, UN 38.3, CE
- Ventilation or winter mode not required
- No maintenance charging required
- 8,000 Watts continuous max. discharge power



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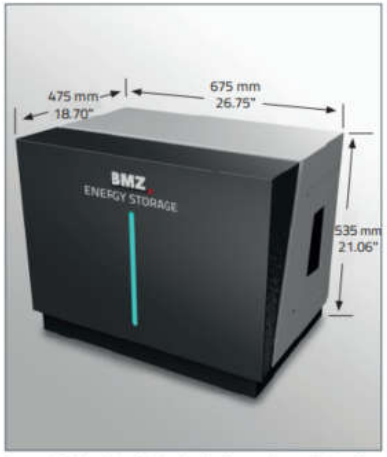
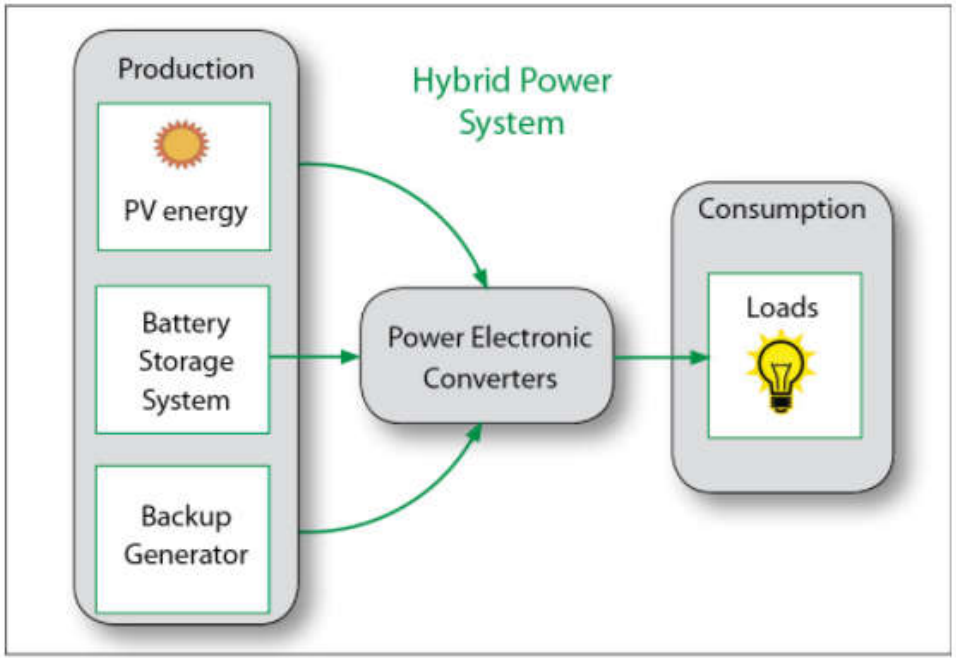
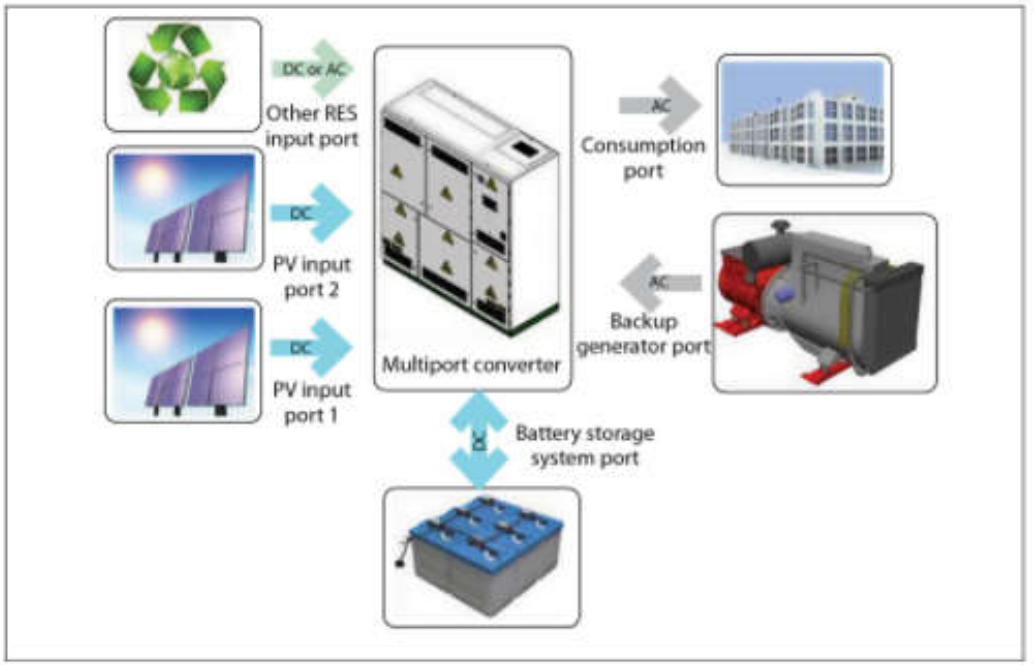


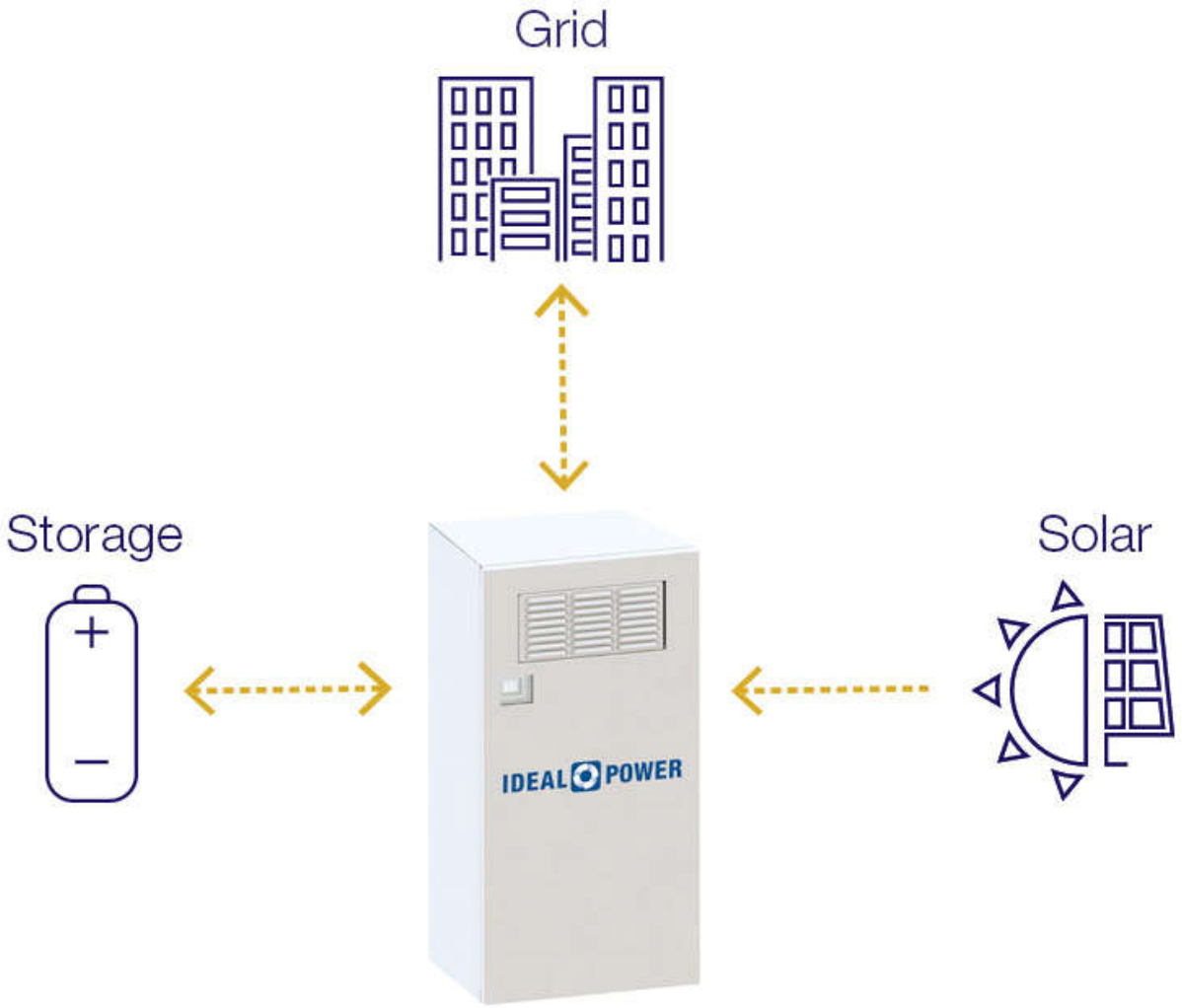
Technical Features	
Nominal voltage	55.5 V
Nominal capacity	121.5 Ah
Nominal energy content	6.74 kWh*
Real energy content	5.39 kWh
Complete cycles	5,000
Depth of discharge	80%
Max. current diascharge	300 A (3 sec.)
IP class	IP 21
Operating temperature	32°F to 113°F
Max. humidity	85% not condensing
Power connection	2 screw terminals 50 mm²
Dimensions (lxwxh)	26.75" x 18.70" x 21.06"
Weight	95 kg/209lbs

What is a multiport inverter?

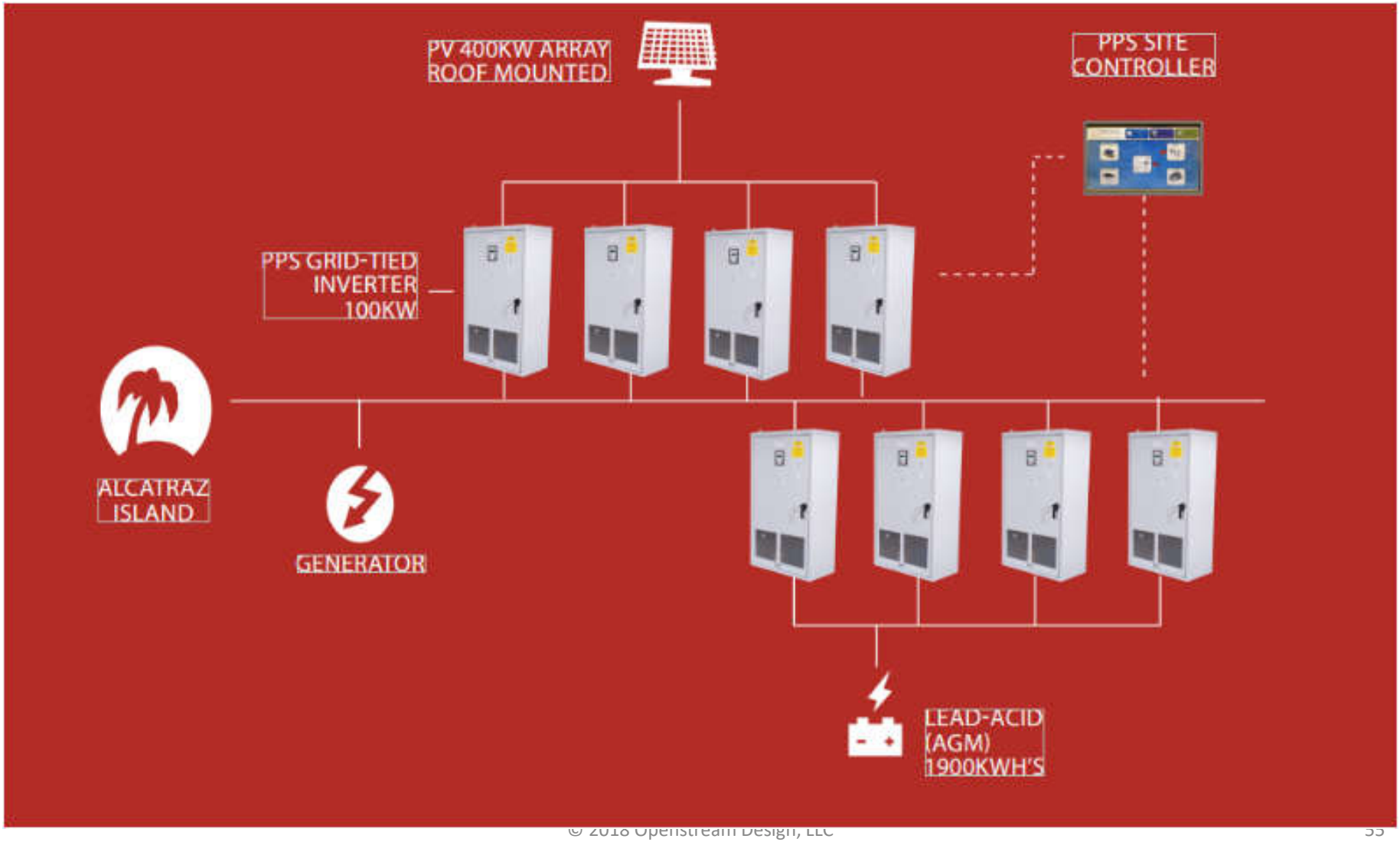




Some Providers



30kW Multiport PCS • Model Number 30C3



Princeton Power Technology:

PPS GTIB-100...

- 96.5% Efficient
- Built-in MPPT for PV
- High Round-trip Efficiency for Battery charging
- Wide Input Voltage Range
- Easily Configured for Microgrids
- Off-grid and On-grid capability

...Making it the best choice for The Rock.

PPS Site Controller...

- Generator Start/Stop
- Short and long term data logging
- Data plotting and exporting to external systems
- Data aggregation
- Remote kiosk display
- Battery Management System
- PV Smoothing
- Modbus Slave Functionality (allows the transmission of any device parameter over Modbus)
- Programmable scheduling (allows scheduling any parameter change to any device at periodic times)

Highlights:

System Size: 400kW (PV), 400kW (Battery)/1900kWh's

Components: (8) 100kW PPS Grid-tied Inverters (GTIB-100), 350kW PV Array, PPS Site Controller, (2) Diesel Generators, and Lead-Acid (AGM) Battery Rack.

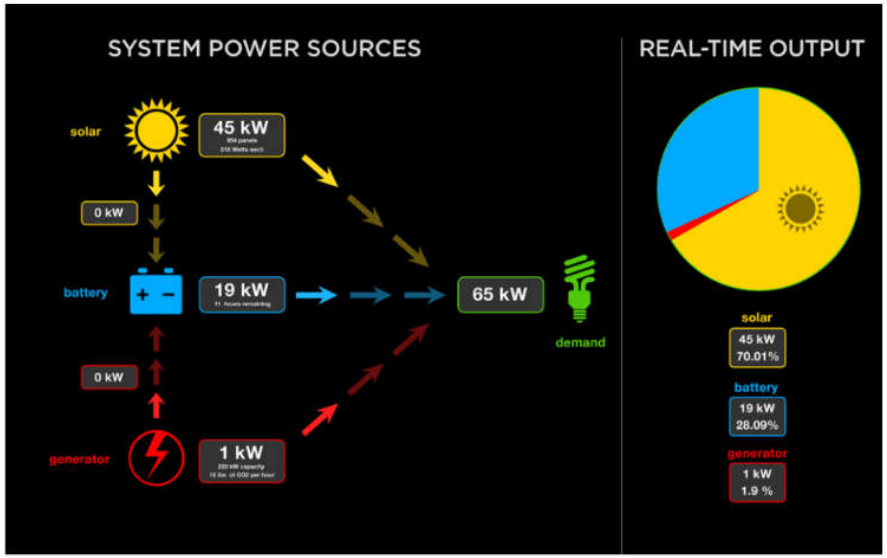
Loads: 50-80kW/day

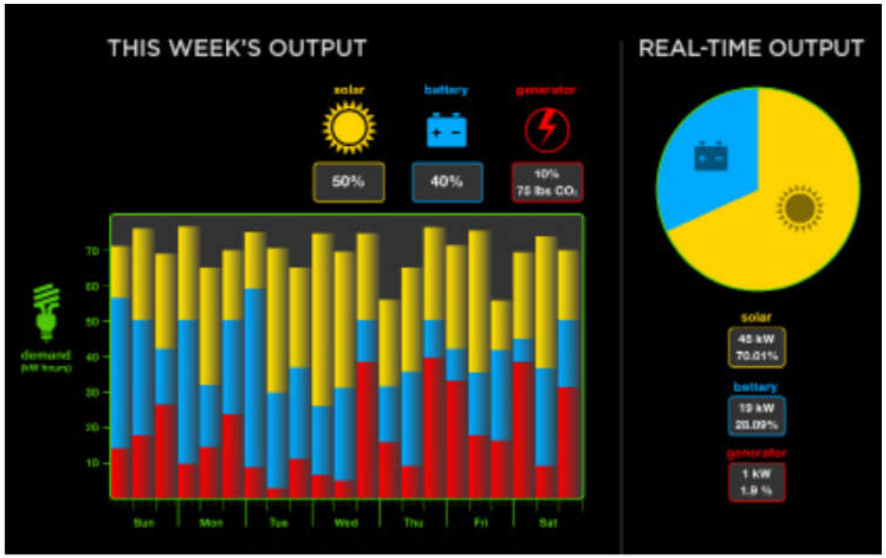
Installation Date: August 2012

Location: San Francisco, CA

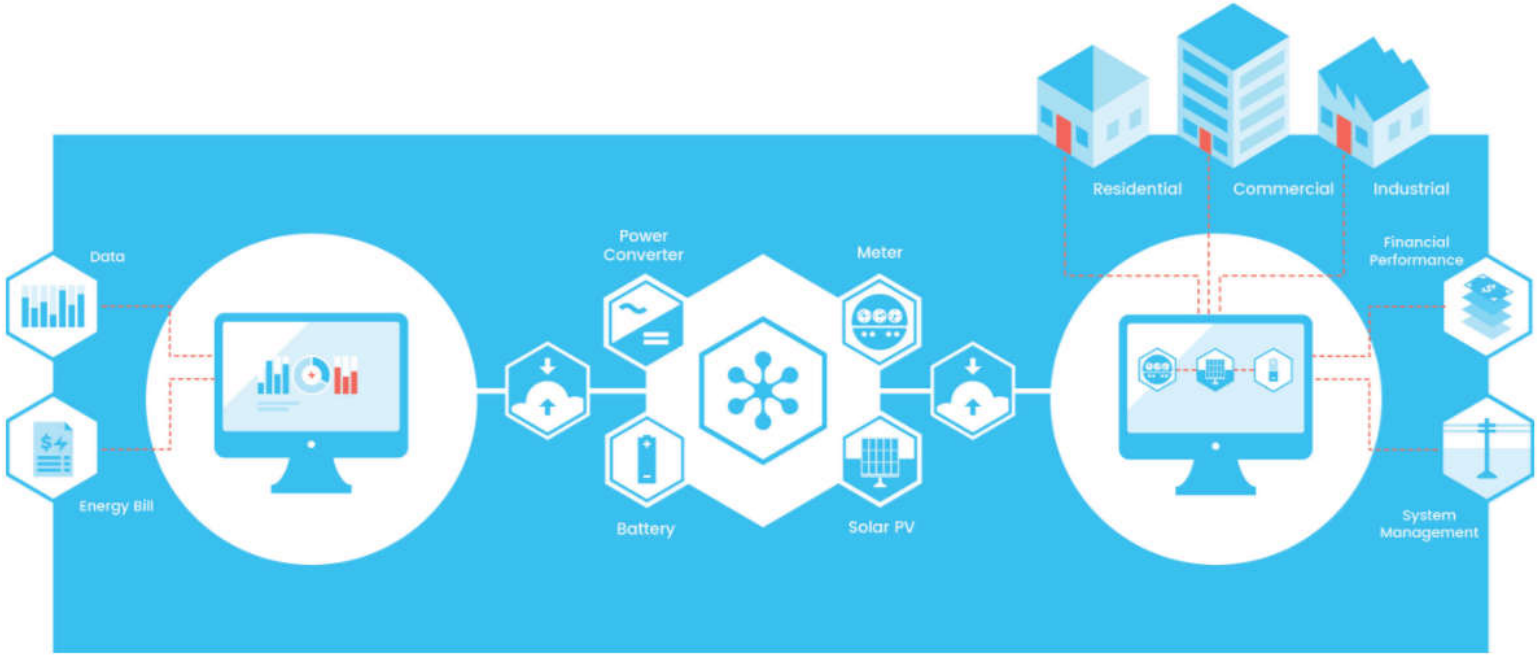
Annual Savings: Reduces approximately 80% of the island's carbon emissions

ALCATRAZ ISLAND MICROGRID INFORMATION KIOSK





GELI and Microgrid Control/Analysis



GELI'S **END-TO-END** PLATFORM

POWERWALL 2 AC

The Tesla Powerwall is a fully-integrated AC battery system for residential or light commercial use. Its rechargeable lithium-ion battery pack provides energy storage for solar self-consumption, load shifting and backup power.

Powerwall's electrical interface provides a simple connection to any home or building. Its revolutionary compact design achieves market-leading energy density and is easy to install, enabling owners to quickly realize the benefits of reliable, clean power.

PERFORMANCE SPECIFICATIONS

AC Voltage (Nominal)	208 V, 220 V, 230 V, 277 V, 100/200 V, 120/240 V
Feed-In Type	Single & Split-Phase
Grid Frequency	50 and 60 Hz
AC Energy[1]	13.2 kWh
Real Power, max continuous[2]	5 kW (charge and discharge)
Real Power, peak (10 s)[2]	7 kW (discharge only)
Apparent Power, max continuous[2]	5.8 kVA (charge and discharge)
Apparent Power, peak (10 s)[2]	7.2 kVA (discharge only)
Imbalance for Single-Phase Loads	100%
Power Factor Output Range	+/– 1.0 adjustable
Power Factor (full-rated power)	+/– 0.85
Depth of Discharge	100%
Internal Battery DC Voltage	50 V
Round Trip Efficiency[1,3]	89.0%
Warranty	10 years

[1]Values provided for 25°C (77°F), 3.3 kW charge/discharge power.
[2]Values region-dependent.
[3]AC to battery to AC, at beginning of life.

ENERGY GATEWAY SPECIFICATIONS

User Interface	Tesla App
Connectivity	Wi-Fi, Ethernet, 3G
AC Meter	Revenue grade
Operating Modes	Support for wide range of usage scenarios
Backup Operation	Optional automatic disconnect switch
Modularity	Supports up to 9 AC-coupled Powerwalls

ENVIRONMENTAL SPECIFICATIONS

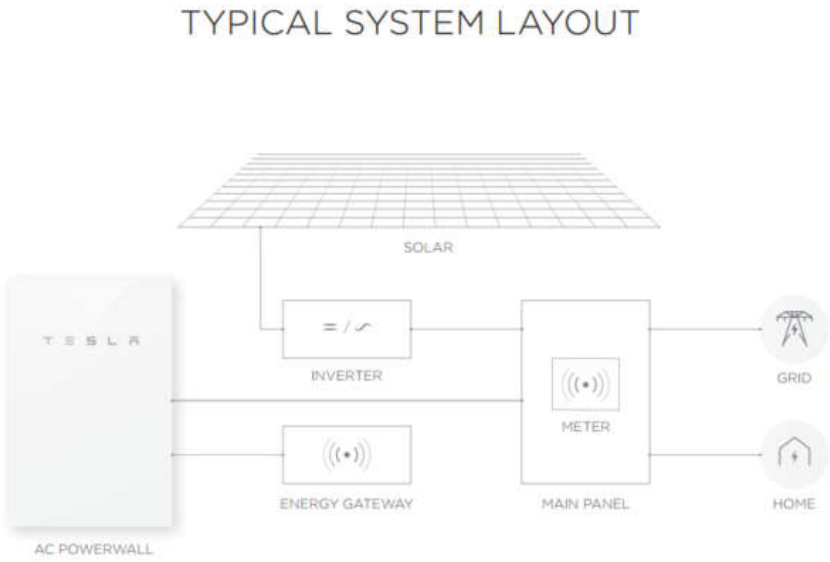
Operating Temperature	–20°C to 50°C (–4°F to 122°F)
Storage Temperature	–30°C to 60°C (–22°F to 140°F)
Operating Humidity (RH)	Up to 100%, condensing
Maximum Altitude	3000 m (9843 ft)
Environment	Indoor and outdoor rated
Enclosure Type	NEMA 3R
Ingress Rating	IP67 (Battery & Power Electronics) IP56 (Wiring)
Noise Level @ 1m	<40 dBA at 30°C (86°F)

MECHANICAL SPECIFICATIONS

Dimensions	1150 mm x 755 mm x 155 mm (45.3 in x 29.7 in x 6.1 in)
Weight	122 kg (269 lbs)
Mounting options	Floor or wall mount

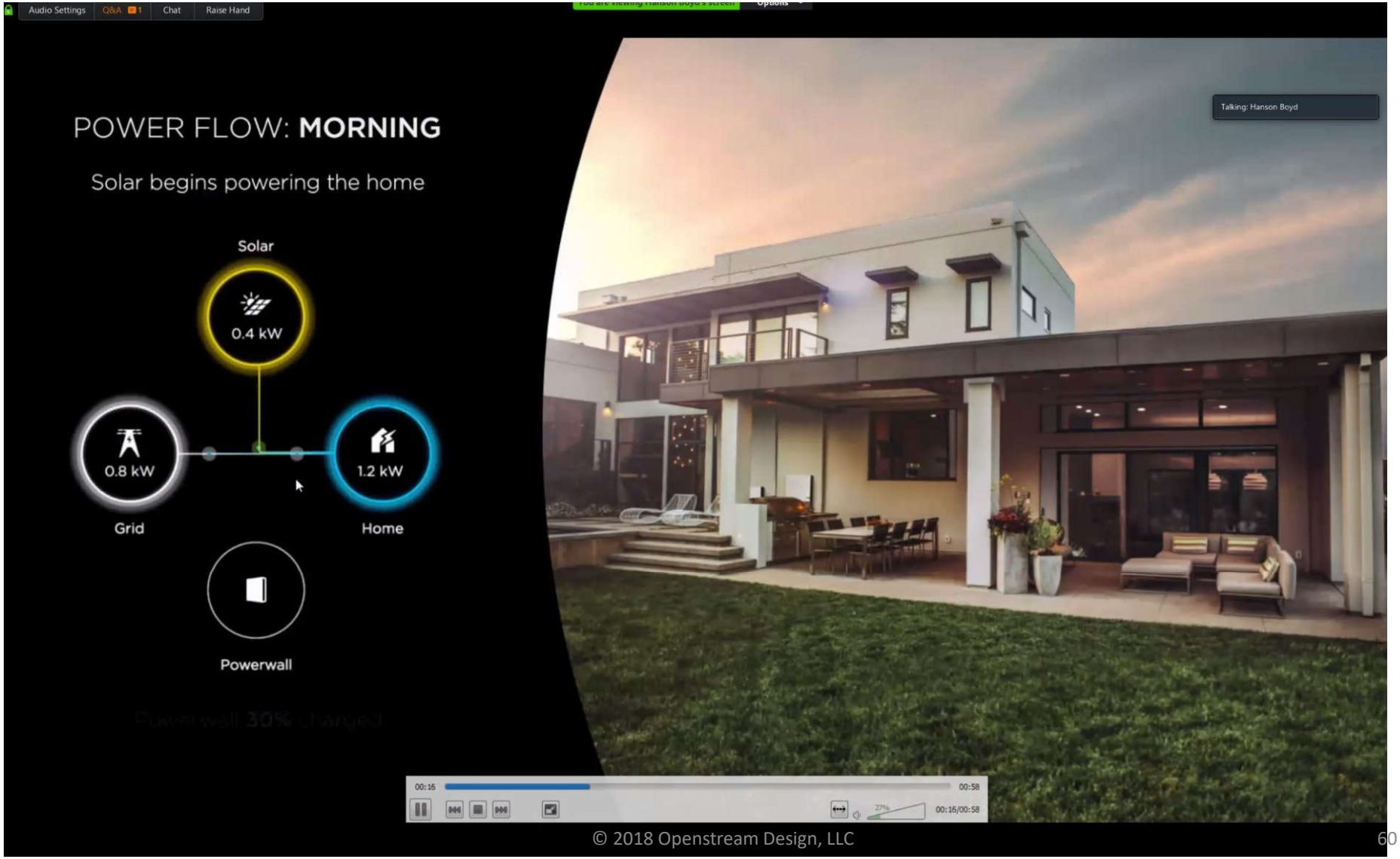
COMPLIANCE INFORMATION

Safety	UL 1642, UL 1741, UL 1973, UL 9540, UN 38.3, IEC 62109-1, IEC 62619, CSA C22.2.107.1
Grid Standards	Worldwide Compatibility
Emissions	FCC Part 15 Class B, ICES 003, EN 61000 Class B
Environmental	RoHS Directive 2011/65/EU, WEEE Directive 2012/19/EU, 2006/66/EC
Seismic	AC156, IEEE 693-2005 (high)



Powerwall specifications

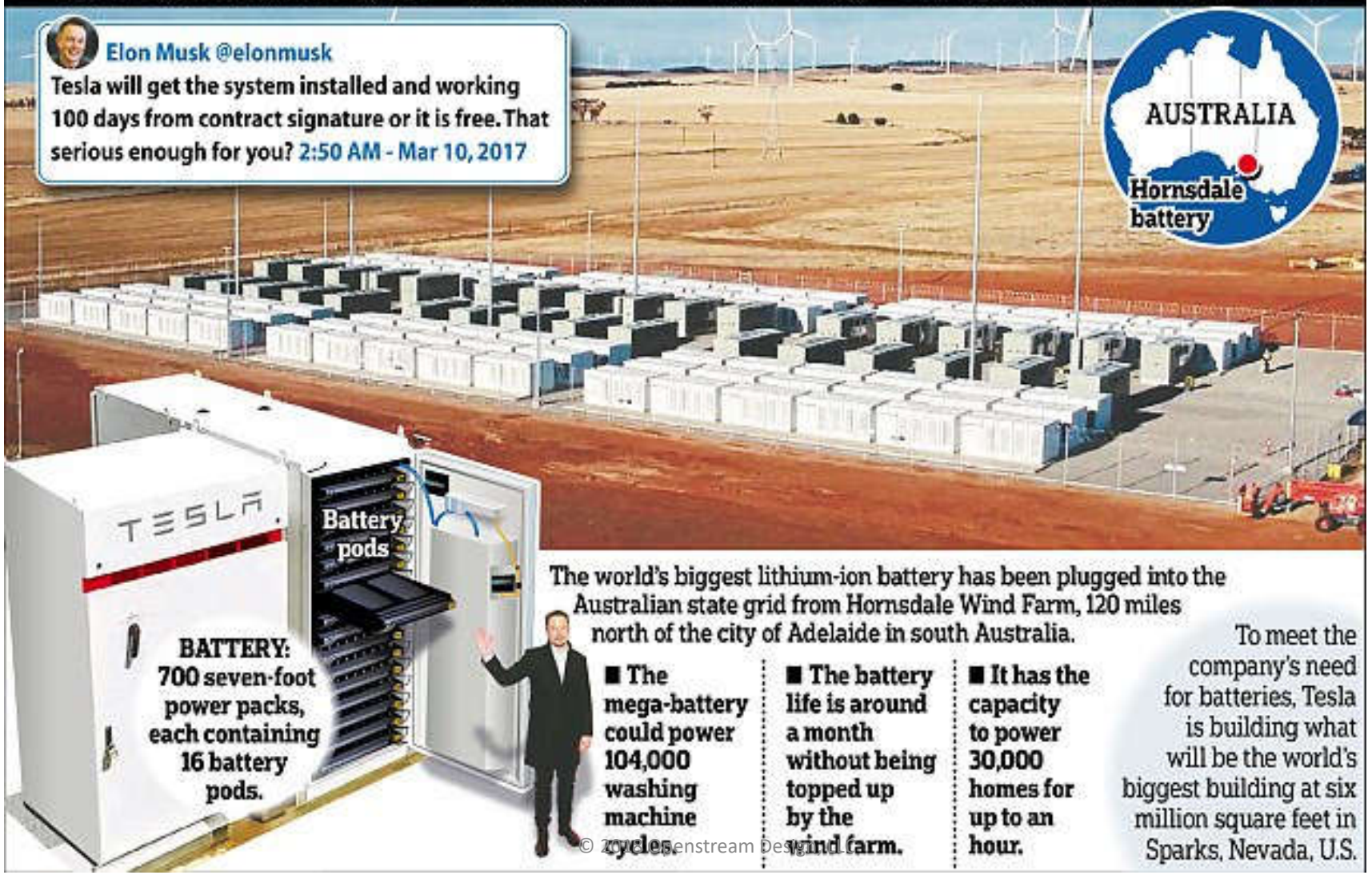
Model	Technology	Price (US$) [a]
Powerwall 1	Lithium-ion	US$3,000
Powerwall 2	Lithium-ion	US$5,500 [b]



Integrated Solution: Sonnen

- 16 kWh storage (LFP)
- Usable at 80% 12.8 kWh
- 8 kW power output (battery inverter – Outback Radian)
- 10,000 cycles

THE GIANT POWER PACK THE SIZE OF A FOOTBALL FIELD



The world's biggest lithium-ion battery has been plugged into the Australian state grid from Hornsdale Wind Farm, 120 miles north of the city of Adelaide in south Australia.

- The mega-battery could power 104,000 washing machine cycles.
- The battery life is around a month without being topped up by the wind farm.
- It has the capacity to power 30,000 homes for up to an hour.

To meet the company's need for batteries, Tesla is building what will be the world's biggest building at six million square feet in Sparks, Nevada, U.S.

STORAGE AND NEC 2017

ARTICLE 480 Storage Batteries

ARTICLE 690 Solar Photovoltaic (PV) Systems

Part VIII. Energy Storage Systems

690.71 **General.** An energy storage system connected to a PV system shall be installed in accordance with Article 706.

ARTICLE 692 Fuel Cell Systems

ARTICLE 705 Interconnected Electric Power Production Sources

Part IV. Microgrid Systems
705.150 System Operation
705.160 Primary Power Source Connection
705.165 Reconnection to Primary Power Source
705.170 Microgrid Interconnect Devices (MID)

N ARTICLE 706 Energy Storage Systems

ARTICLE 710 Stand-Alone Systems

N ARTICLE 712 Direct Current Microgrids

N ARTICLE

706 Energy Storage Systems

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706.6 Multiple Systems

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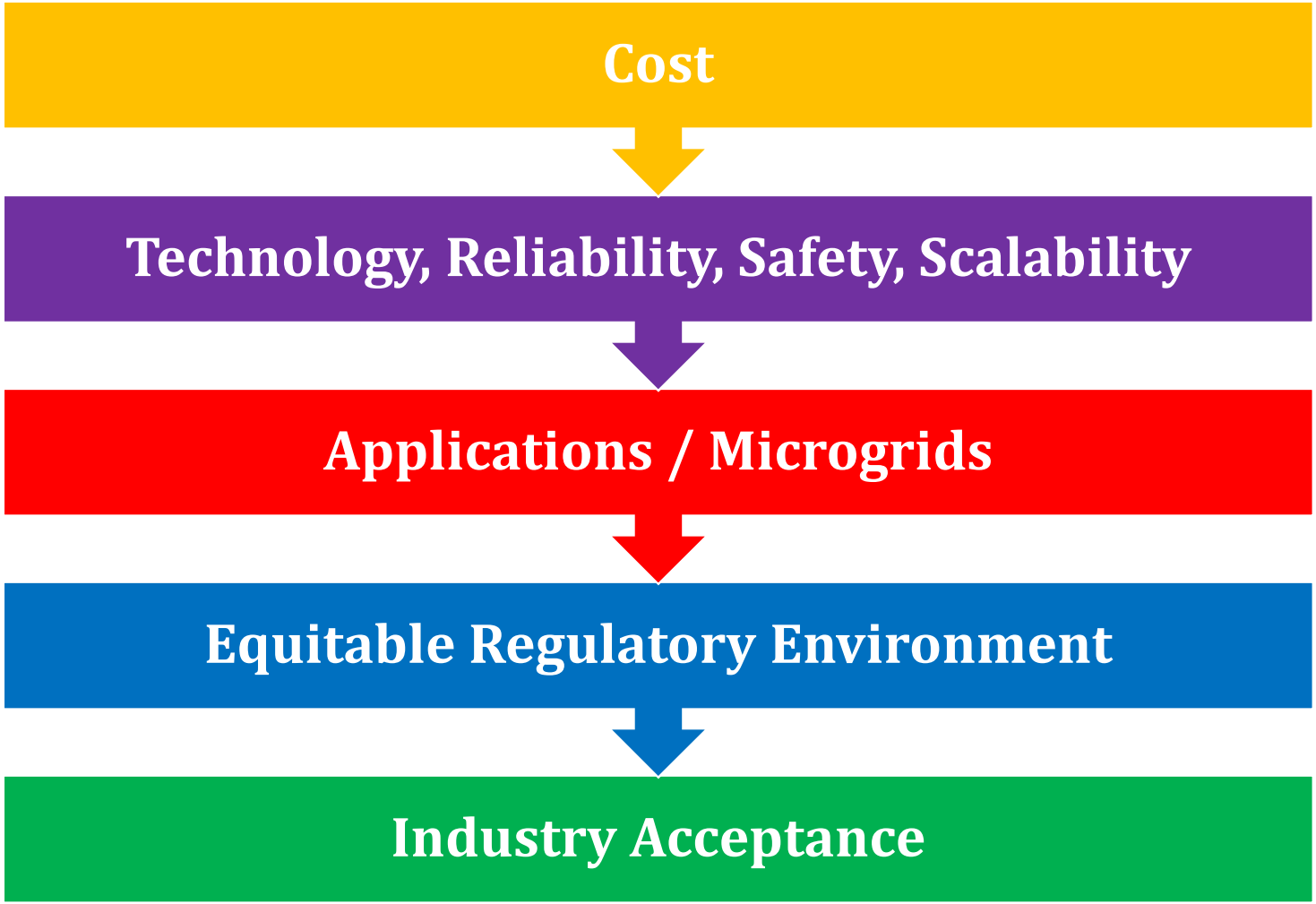
Part I. General

706.1 Scope. This article applies to all permanently installed energy storage systems (ESS) operating at over 50 volts ac or 60 volts dc that may be stand-alone or interactive with other electric power production sources.

Energy storage systems store energy for later use. Wind power and PV systems will generate power when the resource is available, not necessarily when the energy is needed. Energy storage improves the usability of stand-alone alternative energy by storing energy during peak production times so that the energy can be used at a time when wind or sunlight is not available. Increasingly, energy storage is being used to take advantage of utility generating capacity during overnight hours when demand for energy is low. Storing energy may reduce the need to build additional generating stations. Energy storage may be at the generating facility or it may be geographically distributed.



Thank You

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