1. RES Overview
2. US Regulatory Design & Market Constructs
3. Wind Energy and Energy Storage
4. Business Models
5. Storage Basics
6. Technologies
STORAGE

RES Overview
RES Group / RES Americas forged from 145 years of Sir Robert McAlpine Engineering & Construction experience

- Eden Project
- Torness Nuclear Power Station
- 2012 Olympic Stadium
- London Underground
- Concrete Gravity Platforms
# RES Americas Quick Facts

<table>
<thead>
<tr>
<th>QUICK FACTS</th>
<th>EXPERIENCE</th>
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<tbody>
<tr>
<td><strong>Founded:</strong> 1997</td>
<td><strong>Wind &amp; Solar:</strong> 7,000+ MW renewable energy construction portfolio, of which we’ve developed over 3,300 MW.</td>
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<tr>
<td><strong>Technologies:</strong> Wind, Solar, Transmission, Energy Storage</td>
<td><strong>Transmission:</strong> 534+ miles of overhead &amp; transmission lines (up to 345kV) built.</td>
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<td><strong>Services:</strong> Development, Engineering, Construction, Operations</td>
<td><strong>Energy Storage:</strong> 8 MW (16 MW range) constructed. 42MW under construction &amp; 100+ MW in development.</td>
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<td><strong>Locations:</strong> Broomfield, CO (HQ); Minneapolis, MN; Austin, TX; Montreal, Canada</td>
<td><strong>Projects:</strong> 70+ projects in the U.S., Canada, &amp; the Caribbean.</td>
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<td><strong>Employees:</strong> &gt;300</td>
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2014 Renewable Energy Systems Americas Inc. - Proprietary and Confidential
RES Americas

North American Experience

DEVELOPMENT | ENGINEERING
CONSTRUCTION | OPERATIONS

Wind & Solar: Over 7,000 MW renewable energy construction portfolio, of which we’ve developed over 3,300 MW.

Transmission: Over 534 miles of overhead & transmission lines (up to 345kV) constructed.

Energy Storage: 8 MW (16 MW range) constructed/under construction & 100 MW in development.
RES Capabilities

- **RES’ in-house capabilities include:**
  - Project Development & Permitting
  - Construction
  - Engineering: civil, electrical, mechanical
  - SCADA and controls
  - Transmission interconnection
  - Technical analysis & software development
  - Procurement
  - Operations & Maintenance
  - Finance & Contracts
RES Energy Storage - Overview

• RES Energy Storage began in 2009
• Integrated Grid-scale wind and developed SCADA integration for CAES plant, 2011
• Developed, constructed and operating two 4MW/2.6MWh Frequency Regulation plants in PJM and IESO
• Selected by Puget Sound Energy for 2MW/4.4MWh distribution deferral & micro-grid project
• Two 20MW projects under construction in Illinois
• Over 100 MW of storage in development
• Developed RES Energy Storage SCADA Controller based on proven RES Wind SCADA Controller
• Developed control systems for distribution flicker and PV solar ramp control
Why RES - Technical Analysis

- Technical analysis on over 130 energy storage technologies

Flywheels

Aqueous Sodium

High Temperature Sodium

Thermal ES

Super Capacitors

Zinc Air

CAES (Compressed Air ES)

Liquid Metal

Flow Batteries
Example of a completed project

- Ohio PJM
- 4MW/2.6MWh
- Operating in PJM Market since March 2014
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US Market Design & Regulatory Constructs
The contiguous United States consists of 3 separate power grids...
Regions and Balancing Authorities

*Bubble size is determined by acronym width

Note: The highlighted area between SPP and SERC denotes overlapping Regional area boundaries. For example, some load serving entities participate in one Region and their associated transmission owner/operators in another.

As of March 1, 2014
Submit changes to balancing@nerc.com
Most of the population lives in the Eastern US

As a result, there is much greater transmission build out in the East
Terrain Map
Permitting (Federal Lands may be difficult to permit)
Renewable Portfolio Standard Policies

29 states + Washington DC + 2 territories have a renewable portfolio standard
(9 states and 2 territories have renewable portfolio goals)

Renewable Portfolio Standard Policies

www.dsireusa.org / September 2014

- Renewable Portfolio Standard
- Renewable Portfolio Goal
- Solar Water Heating Eligible

- Minimum Solar or Customer-Sited Requirement
- Extra Credit for Solar or Customer-Sited Renewables
- Includes Non-Renewable Alternative Resources

States

- WA: 15% x 2020*
- OR: 25% x 2025 (large utilities)*
  5% - 10% x 2025 (smaller utilities)
- CA: 33% x 2020
- NV: 25% x 2025*
- AZ: 15% x 2025*
- NM: 20% x 2020 (IOUs)
- TX: 5,880 MW x 2015*
- HI: 40% x 2030

- MT: 15% x 2015
- ND: 10% x 2015
- SD: 10% x 2015
- KS: 20% x 2020
- MO: 15% x 2021
- OK: 15% x 2015

- MN: 26.5% x 2025 (IOUs)
  31.5% x 2020 (Xcel)
  25% x 2025 (other utilities)
- WI: 10% x 2015
- IA: 105 MW
- IL: 25% x 2026
- IN: 15% x 2025†
- WV: 25% x 2025†
- VA: 15% x 2025*

- MI: 10% x 2015†
- NY: 29% x 2015
- OH: 12.5% x 2026
- SC: 2% x 2021
- NC: 12.5% x 2021 (IOUs)
  10% x 2018 (co-ops & munis)
- VT: 20% x 2017
- ME: 30% x 2000
  New RE: 10% x 2017
- NH: 24.8% x 2025
- MA: 22.1% x 2020
  (+1% annually thereafter)
- RI: 16% x 2020
- CT: 27% x 2020
- VT: 2020
- PA: 18% x 2021†
- NJ: 20.38% RE x 2021
  + 4.1% solar x 2028
- DE: 25% x 2026*
- MD: 20% x 2022
- DC: 20% x 2020
- SC: 20% x 2025

- OK: 15% x 2015
- TX: 5,880 MW x 2015*
- KS: 20% x 2020
- MO: 15% x 2021
- OK: 15% x 2015

- Guam: 25% x 2035
- USVI: 30% x 2025
Politics (Popular Vote in 2008 Presidential Election)

Democrat

Republican
U.S. Electric Industry Average Revenue per Kilowatthour, January 2014

Source: Energy Information Administration
The Result: US Installed wind capacity
Storage in the regulatory landscape: A few examples

- Is energy storage a generator, or a load?
  - Utilities have to keep discussions of generation and load separated and in organized markets suppliers and distributors are different entities

- How should energy storage be taxed?
  - Generation equipment is taxed differently from transmission and distribution equipment

- Is the cost of energy for charging the same as the price for discharging?
  - Paying retail rates when charging and only receiving wholesale rates when discharging doesn’t make for a good business case!

- Can I perform a Transmission service from the Distribution system?
  - It is far quicker and cheaper to connect to the low voltage distribution system
Arbitrage! Otherwise known as....

Let’s imagine that:

- I can buy power for $20/MWh at night and sell it on-peak for $70/MWh
- I have a 1MW/2MWh battery (2 hours of storage)
- My arbitrage opportunity is therefore:
  \[(\$70-\$20) \times 2 \text{ hours} \times 365 \text{ days} = \$36,500 \text{ per year}\]

- A 2hour battery excluding the cost of building it is about $500/kWh today (but projected to drop to around $350/kWh in a few years)
- The battery in the above example would therefore cost $1,000,000
- Clearly a 28.6 year payback is not a great opportunity!
Shifting wind energy from one period of the day to another is effectively ‘arbitrage’ by a different name.

Some uses for storage with wind:

1. Ramp rate control
2. Reduction of wind integration charges
3. Potential to provide a behind-the-fence service
   - E.g. Frequency Regulation

As the cost of energy storage continues to fall it is expected that its co-location with wind may accelerate

- Especially energy storage technologies for which it is cheap to add additional ‘hours’ (e.g. compressed air or thermal storage)
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Business Models
Project viability is related to the Cost of Energy Storage

The cost of Energy Storage has dropped 40% since 2013

A thousand profitable projects have just now come into existence
Energy Storage

- **Energy Storage: The Swiss Army Knife of Grid Resources**

- **Multiple Values & Uses from a Single Device**
Typical Durations

- Obviously the duration of energy storage required affects the cost.
- It is obvious that some services will therefore need to yield higher average hourly revenues than others!
  - **Frequency Regulation** (15 minute to 1 hour)
  - **Transmission or Distribution Deferral** (2 to 4 hours)
  - **Peaker Plant Replacement** (2 to 6 hours)
  - **Merchant Wind in the Day Ahead Market** (2 to 10 hours)
  - **Baseload Renewables** (50 to 200 hours)
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Frequency Regulation
What is Frequency Regulation?
- Injection & Withdrawal of real power on second-by-second basis
- Purpose: to keep grid frequency within tight bounds.
- Market size is about 1% of load

How is Frequency Regulation implemented?
- Generators reserve a capacity range, and vary output within this range in response to an AGC (Automatic Generator Control) signal

How is Frequency Regulation Provided / Purchased?
- In ISO areas, the ISO creates an hourly market for FR services, and resources bid into this market on a day-ahead basis. The ISO pays the providers, and recoups this cost from the load serving utilities, in proportion to their load profile in the ISO.
- In non-ISO areas, the local utilities are required by FERC to meet FR standards, and do so using their own resources or through bi-lateral contracts.
Frequency Regulation

- **Why is Battery Based Regulation more Effective?**
  - Fast ramping resources such as batteries can correct frequency imbalances much more effectively per MW than slow ramping resources.

- **Why will Battery Based Regulation be Paid more per MW?**
  - FERC ruling 755 requires all ISOs to ‘pay for performance’ in their regulation market
  - Similar FERC ruling (784) implemented in non-ISO areas.

![Regulation Effectiveness Graph](image-url)
Frequency Regulation

Market Models

- Merchant
- FERC 784
- Hedged

Benefits

- Faster and More Efficient than Gas or Coal Generation.
- Can use Renewable Energy to Provide Service.
Even with an energy neutral signal (in PJM it is neutral over ~ 15 minutes) a battery will hit zero state of charge over time due to its round trip efficiency.

RES needs to recharge the battery while minimizing its reduction in ‘Performance Score’ and has developed algorithms to deal with this issue.
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Solar PV integration
Clouds & PV Solar

- Extreme Ramps
- 15-60 Minute Variability
- Voltage & Frequency Fluctuations
- Expensive Integration
- Poor Power Quality & Reliability

Puerto Rico

- 4 million population
- Energy cost on island ~$290/MWh
- 400MW of solar PPAs at $150/MWh+
- All PV on island must meet <10%/minute ramp rates plus other requirements, per PREPA
- Energy Storage required to integrate all Solar
PV / Wind Ramp Control

Market Models

- Interconnection Requirements (Puerto Rico, Hawaii)
- Increase value of PV PPAs
- Mitigation of DG Variability on Distribution, sale to Utility.

Benefits

- Much faster than available carbon based balancing.
- Improve Power Quality.
- May be rate based.

Webberville 30MW PV on a Partially Cloudy Day

Rooftop PV causing Voltage Fluctuations on local Distribution. SDG&E Rate Case 2012
By employing a simple PID controller, we can smooth out the production.

An energy storage system can charge/discharge to keep the grid production at the smoothed level.

Problem: the smoothed output has no regard for the battery.
If we simply follow the smoothed line, eventually the battery is going to have a SoC which renders it unable to respond to an event.

So how can we best situate the battery’s SoC so that it is ready to respond to what is likely to happen in the future?
The Result
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Micro Grids
Microgrid - Isolated

**Market Models**
- Villages, Islands, remote Mines and Oil & Gas extraction. Sale or services contract.

**Benefits**
- Allows higher RE Penetration.
- Reduces Diesel consumption & maintenance. Allows higher Diesel efficiency.
Wind & Solar is not generally economic against $2/MMBTU gas.

Wind & Solar is very economic against $370/MWh diesel.

Gas fuel cost (8800 Heat Rate)
- 2008 ($6.60/MMBTU) - $58.00/MWh
- 2012 ($2.00/MMBTU) - $17.60/MWh

Diesel fuel cost (Yellowknife)
- 2008 ($3.70/gallon) - $220/MWh
- 2012 ($5.29/gallon) - $370/MWh

2008 – 2012
- Nat Gas: 70%
- Diesel: 68%
Offsetting Diesel on Islanded Grids with Renewables

- **Mettlakatla, Alaska**
  - 1.5MWh battery to support Hydro, Diesel
  - 3 year payback from Diesel and O&M Savings
  - 1997 project – Diesel $1.20/gallon
**Microgrid - Outage Mitigation**

- **Glacier, Washington. RES’ first Distribution deferral / Microgrid Project. COD July 2015.**

**Market Models**
- Sale to Distribution Utilities
- Large Loads, Military Bases
- Mobile Energy Storage - On Wheels

**Benefits**
- Additional value on top of distribution deferral.
- Storm Mitigation.
- Could support critical facilities.
STORAGE
Peakers
Background to the Market

Peaking Capacity / Resource Adequacy

Market Models

- AB2514
- Capacity Contracts
- Direct Sales to Utilities

Benefits

- Easier Siting - No Emissions, No Gas Infrastructure Required.
- Modular Sizing - Less Transmission
- No Minimum Run Times, No Minimum Setpoints.

2014 Renewable Energy Systems Americas Inc. - Proprietary and Confidential
• What are “Peakers”?
  - Simple cycle combustion gas turbines, used for reserve capacity, summer afternoon peaks. Most peakers have capacity factor < 1%. Rarely on for more than 5 hours

• Running out of Excess Capacity - Capacity Prices Rising.
Energy Storage cannot compete today head-to-head for capacity cost ($/kW-year), but provides additional values:

- Much faster ramping (instant!)
- No minimum run times
- No emissions cost – no air permits
- Provides frequency regulation or spinning reserve – no cost to spin
- Arbitrage energy on spot market
- Reduced need for coal cycling, reduces emissions and O&M costs
- May reduce transmission congestion
- Reduce wind curtailments
- No minimum generation – 200% range versus ~70% range for a CT
- No cooling water usage
- Average usage of US Peakers 70 hours/year, <1%
- However, Gas Peakers have unlimited total duration, while Storage is limited in duration.

What is the value of an Energy Storage Peaker?
Energy Storage could turn variable wind into baseload power

Utilities pay for reliable capacity. $\text{Power} = \text{Capacity} + \text{Energy}$

Utilities may pay higher balancing / integration costs for variable wind.

- When combined with a wind forecast, a bid strategy with Energy Storage could realize additional revenue by shaping the day ahead output to target expected high value periods.

- In non-organized markets, some transmission providers charge “Wind Integration Fees”, which are intra-hour balancing charges. Wind owners can self provide to avoid these fees.

  - Example: Bonneville Power Administration, covering the Northwest US, requires a \$5.70/MWh integration fee for intra-hour balancing.
Market Models
- Higher value PPAs by using Shaped Power

Benefits
- Sell FR or Spinning Reserve during non-shifting periods
Market Models

- Add DC to PV plants for greater CF on same MW Interconnection, ES used to capture clipped energy.

Benefits

- Higher CF, Higher ROI
- Provide Ramp control
- Sell FR or Spinning Reserve during non-shifting periods
STORAGE

Transmission & Distribution
Deferral
Transmission and Distribution Deferral / Replacement

- Energy Storage can provide peak shaving, that allows utilities to defer the installation of new transmission lines, or upgrade transformers in substations.
- Electrical Power Research Institute (EPRI, the primary US energy research, funded by 95% of all utilities), states this is highest value energy storage market.
- Favors mobile energy storage.
- Issue: US transmission owners barred from owning generation. Some consider energy storage to be generation.

Installed projects
- 1MW NaS - AEP Charleston, WV, 2006 - Deferred substation upgrades
- 2MW NaS - AEP Milton Station, WV 2008 - Deferred equipment upgrade, improved circuit performance
- 4MW NaS - AES / MidAmerican Presidio, TX, 2010, Deferred transmission
Storage can be used to control flow on congested elements.

Storage can supply voltage support at the end of long distribution lines.

Market Models
- Direct Sale to Distribution Utilities.

Benefits
- Economical Deferral of Capital Upgrades that can be Rate Based.
- Reduces Risk of Upgrade.
- Modular ES may be moved as Required.
Transmission Deferral

Market Models

- Direct sale to Transmission Utility
- Services Contract
- FTRs / Hedging

Benefits

- Reduces Risk about block load additions, Trans. Constr. Delays
- ES can be added incrementally, moved and redistributed as system requirements change

Congestion Simulated in 2012 PROMOD Model on West Bellaire to Brues Transmission Line

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Congestion ($ Millions)</th>
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<tbody>
<tr>
<td>Without Storage</td>
<td>$13.87</td>
</tr>
<tr>
<td>With Storage</td>
<td>$4.15</td>
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</table>

STORAGE

Other uses
Commercial & Industrial

Market Models
- Demand Charge Reduction
- Reduced use of Peak Power Tariff prices
- Allows C&I Facility to enter DR Market.
- UPS

Benefits
- Sell Distributed Generation to same C&I customer.
Large C&I customers pay two separate portions of their bill:

1. Energy – kWh
2. Demand - kW

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<tr>
<td>Basic customer charge</td>
<td></td>
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<tr>
<td>On-peak KWH</td>
<td>934,404 kwh x $0.04994</td>
</tr>
<tr>
<td>Off-peak KWH</td>
<td>1,466,796 kwh x $0.04494</td>
</tr>
<tr>
<td>On-peak KW</td>
<td>4,309.00 kw x $19.56000</td>
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</tbody>
</table>

Example of Demand Charge Reduction
Other Secondary Services

- Additional Revenue Streams or Benefits on Energy Storage Projects
  - Spinning Reserve
  - Volt/VAR Power Quality Services
  - Replace Dynamic VAR in RE plants
  - Demand Management
  - Black Start Service

Market Models
- Consider Secondary Services for all Energy Storage Projects

Benefits
- Increase ROI on Energy Storage projects
Storage Basics
Energy Storage (for our purposes) means storage that allows a complete round trip back to Electrical Energy.

Electricity ➔ Storage Medium ➔ Electricity

Grid Energy Storage is Not:
AC vs DC

- Alternating Current (AC)
- Grid Current

- PCS (Power Conditioning System)
- Inverter (DC to AC)
- Rectifier (AC to DC)

- Direct Current (DC)
- Battery Current
What is a Battery Cell?

- Primary Cell:
  - Chemical Energy ➔ Electricity

- Secondary (Rechargeable) Cell:
  - Electricity ➔ Chemical Energy ➔ Electricity
MWh Energy VS. MWh Energy Storage

MWh of Energy

MWh of Energy Storage
What is State of Charge (SOC)?

- State of Charge (SOC) is the Fuel Gauge on a Battery System
  - 100% SOC is Full
  - 0% SOC is empty
What is a Cycle? What is Cycle Life?

- **One Cycle**: a single Charge and Discharge of a Battery

- **A Cycle** may mean discharging from 100% State of Charge to 0% State of Charge (A full cycle), or a smaller range of State of Charge (A partial cycle)

- **Cycle Life**: The number of times a battery may be cycled (As the cycle is defined), until the battery has degraded to a certain capacity, such as 80% of original capacity

- **Beware**: Both terms are manipulated by manufacturers
What is Battery Efficiency?

Battery Efficiency = kWh Discharged / kWh Charged

- Where the battery ends with the same State of Charge as it started with
- Battery Efficiency is a Slippery Term
  - Where is it measured? At the Battery or at the AC terminals of the PCS?
  - Is it measured for a full cycle (100% to 0% SOC), or a partial cycle?
  - Does the denominator include energy for heating/cooling and control equipment?
What is C-Rate?

- C-Rate = $1/#$ hours to discharge the battery fully at the maximum MW output
- Batteries are designed to operate at a discharge rate no higher than their C rate
- Some chemistries are capable of higher C rates than others
  - Example: A Battery that can fully discharged from 100% SOC to 0% SOC in 10 minutes (0.166 hours), is a 6C battery ($1/0.166$)
  - Example: A Battery that can fully discharged from 100% SOC to 0% SOC in 4 hours, is a 0.25C battery (more commonly called a C/4 battery)
Power Application VS. Energy Application

- Power Vs. Energy Application is based on the ratio of MW/MWh for an Energy Storage system

  - High MW/MWh ratio = Power Application = High C rate

  - Low MW/MWh ratio = Energy Application = Low C Rate
Battery Degradation

What effects battery degradation?

- Calendar life
- Cycling use
- Temperature*
- Rate of Discharge of Cycles*
- Average SOC during life*

* Depends on Battery Chemistry
Cells in a series string must run out of energy at the same time

Like a weak link in a chain, a low SOC cell will fail a string or damage a cell

Active measures are taken to balance cells so they run out (or are fully charged) at the same time
Lithium Batteries - Why do they Dominate the Market?
Lithium Batteries Come in These Exciting Flavors

- LCO = Lithium (Li) Cobalt Oxide
- NCA = Li, Nickel Cobalt Aluminum
- NCM = Li, Nickel Manganese Cobalt Oxide
- LFP = Li, Iron Phosphate
- LTO = Li, Titanate
- LMO = Li, Manganese Oxide
Lithium Cell Form Factors

- **Cylindrical**
  - 7 ounces,
  - 1.3” x 4.5”
  - 4.5 ampere hours

- **Pouch**
  - 9 ounces
  - 3.5” x 5.5” x 0.4”
  - 10 ampere hours

- **Prismatic**
  - 13 pounds
  - 16.5” x 6” x 2.4”
  - 200 ampere hours
Issues with Lithium Batteries (Varying with Chemistry)

- Restricted SOC cycle band
- Manufacturing cost
- Toxicity
- Recyclability / Ability to Landfill
- Thermal runaway
- Balancing issues
- “Knee off” degradation curve
- Sensitivity to temperature
“The reduced peak of self-heating rate of LiFePO4 based cells makes them the safest cell Li-ion batteries on the market today”

- Sandia National Laboratories 2012
- 8 cell module
- Battery module controller and cell balancing (part of Battery Management System)
- Racks
- Intermodule connectors
STORAGE Technologies
Matching a Technology to an Application can be Complicated

- MW / MWh storage
- Cycle Life and Cycle Life Degradation
- Lifetime Degradation
- Efficiency

The above are affected by C rate, depth of discharge (DOD), duty cycle, environmental temperature, ancillary loads, self discharge

Locational / Footprint Issues. Some technologies require specific geology and some require a large footprint

Environmental hazards: Some technologies use chemicals that may constitute an environmental issue

Selection is more than just a $ price!
What does it take to be a Grid Energy Storage Battery?

- Long cycle life
- Long calendar life
- Low $/kWh
- Cells can remain balanced in long high voltage strings
- Highly reliable
- Tight manufacturing processes that result in identical cells
Batteries That are Not Grid Energy Storage Batteries

Common Batteries Not Used for Grid ES
- Lead Acid
- NiCAD, NiMH

Why Aren’t they Used?
- Poor cycling characteristics
- Low energy density
- Memory effect (NiCAD)
- High cost per kWh (some)
Reminder: Why Lithium Batteries Dominate

50 GWh in annual battery production by 2020
Enough for 500,000 Tesla cars
Powered by renewable energy
Net zero energy factory
**Energy Storage - Lithium Batteries**

**Development / Production Status**
- In large scale production
- Continuing improvements driven by development

**Market**
- Storage duration < 4 hours
- Fast response

**Costs**
- $350/kWh - $1000/kWh for integrated systems
- Long term capacity & availability warranties available

**Vendors**
- BYD, Tesla (Panasonic), LG Chem, Samsung, Toshiba, Saft, Microvast, NEC
Energy Storage - Pumped Hydro

**Pros**
- Low cost energy storage
- Unlimited cycling
- 20 hour plus storage

**Cons**
- Site Dependent
- No PHES completed for 20 years in USA due to environmental concerns
Energy Storage - Pumped Hydro

Development / Production Status
- Presently accounts for 99%+ of all energy storage
- 18.4GW currently under construction for completion by 2019, 11.8GW in China alone.
- No new pumped hydro construction in USA for 20 years
- Expensive to develop sites

Market
- Extremely long term duration > 24 hours
- Large scale load leveling

Costs
- $1200 to $2500/kw, but only $40 to $80/kWh
Energy Storage - Flywheels

**Pros**
- Very long cycling and calendar life
- No toxic materials
- Fast response

**Cons**
- More expensive
- Potentially hazardous failure modes
- Higher standby losses
Energy Storage - Flywheels

Development / Production Status
- In modest scale production

Market
- Frequency Regulation and other fast response services.

Costs
- $2000/kW for 15 minutes storage systems

Vendors
- Beacon, Temporal Power, Vycon, Pentadyne Power
Energy Storage - Compressed Air Energy Storage (CAES)

Pros

- Fueled vs. non Fueled CAES
- Low Energy Storage Costs
- Unlimited cycling potential

Cons

- Large Scale only
- Site Dependent (salt caverns)
- Low efficiency (60% - 70%)
Energy Storage - Compressed Air Energy Storage (CAES)

Development / Production Status
- Fueled CAES - 2 large scale plants constructed > 20 years ago
- Non-fuel CAES in mid development

Market
- Long duration > 10 hours
- Large scale load leveling

Costs
- $500 - $1500/kW, plus storage costs (potential)
- Tank Storage $200/kWh
- Cavern Storage as low as $6/kWh

Vendors
- Dresser-Rand (Fueled)
- General Compression, LightSail, Bright Energy, Highview (non-fueled)
GC use salt caverns and there is an interesting alignment with wind potential

- Wind in the Texas and Oklahoma panhandles and the Great Plains
CAES for Wind Energy: General Compression (GC)

GC use salt caverns and there is an interesting alignment with wind potential

- Offshore wind in Europe

Northern Europe Wind

Salt Deposits in Northern Europe
Energy Storage - Thermal Energy Storage

Pros

- Site independent
- Low storage only costs ($75/kWh)
- Unlimited cycling potential
- Non-toxic and benign

Cons

- Very low efficiency, 50%-60%
Energy Storage - Thermal Energy Storage

Development / Production Status
- Early-mid development

Market
- Long term storage > 4 hours
- Markets that can sustain low efficiency.

Costs
- Unknown. Potentially as low as $35/kWh for storage.

Vendors
- Isentropic, Siemens
Energy Storage - Super Capacitors

Pros
- Extreme high C rate (1000)
- High efficiency
- Degrade Like Batteries (calendar life, temperature)

Cons
- High cost per kWh
- Straight line kWh/V results in less efficient PCS
Energy Storage - Super Capacitors

Development / Production Status
- In large scale production

Market
- Extreme short duration (seconds)
- High C-rate, fast response

Costs
- $100,000/kWh

Vendors
- Maxwell, Elna, Cooper-Bussman
High Temperature Batteries

Pros
- Well proven
- Environmentally invariant
- Both NaS and NaNi available

Cons
- Limited Cycle life
- Low efficiency due to high ancillary loads
- Catastrophic fire issues
Energy Storage - High Temperature Batteries

Development / Production Status
- Medium scale production (300MW / ~1800MWh in service today)
- 30MWh NaS battery Presidio, Texas used for transmission deferral

Market
- Medium duration - 2 hrs to 8 hrs
- Markets that can sustain lower efficiencies
- Daily cycling (not good for standby due to standby losses)

Costs
- $600/kWh for integrated systems at 6 hour rate

Vendors
- NGK Insulators, GE (Durathon), FIAMM
Flow Batteries

**Pro**
- “Only battery with an off switch”
- Extremely long cycling potential

**Con**
- Low energy density
- Large quantity acidic electrolyte
- Low efficiency - 70%
Energy Storage - Flow Batteries

Development / Production Status
- Late development and early production

Market
- Medium to long storage duration, 3 - 12 hours

Costs
- $340 - $600/kWh

Vendors
- Enervault, American Vanadium, UET, RedFLOW, Zinc-Air
“True” versus “Hybrid” Flow Batteries

**True Flow Battery**
- “Chemicals” in two tanks react by passing ions through ionic membrane, creating or storing electricity in the liquid.
- Power isolated from Energy, bigger tanks = more energy
- Potentially unlimited cycling

**Hybrid Flow Battery**
- Zinc is plated on one electrode, bromine or chloride is complexed on other electrode for storage
- Zn Chloride, Zn Bromide, Zn Iron
- Power is not isolated from Energy
- Potentially unlimited cycling
Other Grid Energy Storage Batteries

Aquion Aqueous Sodium Battery
LMB Liquid Metal Battery
EOS Zinc Air Battery

**Pros**
- Low cost potential
- High C rate (LMB)
- Non-Toxic (Aquion)

**Cons**
- Low energy density (Aquion)
- Very high temperature (LMB)
Energy Storage - Other Grid Energy Storage Batteries

Development / Production Status
- Aquion - early production
- EOS - late development - early production
- LMB - mid development

Market
- Various - long duration for EOS and Aquion (8 hours +), long & short for LMB

Costs
- Varying, but as low as $140/kWh for long duration
Metal Air Batteries

- Breathes oxygen in on charge and out on discharge
- Potential for lowest cost for a battery, environmentally benign, great energy density
- One of two reactants, air from oxygen, is free and available

Analogy
- Burning a tank full of gas requires 850 kg of air the car doesn’t have to carry