WHY BATTERY STORAGE IS IMPORTANT
The Energy Sector is Being Transformed

A virtuous cycle is unlocking the economic, social and environmental benefits of renewables.
By 2050, total energy-related CO$_2$ emissions will need to decrease to below 10 Gt/yr. CO$_2$ emissions from the power and buildings sectors will be almost eliminated.
The end-use sectors transition: untapped area

**Transport**
- Will traditional car makers able to catch up?
- Significant biofuel trade
- Materials needs (e.g. rare earth for EVs)

**Industry**
- Industry is the most challenging sector

**Buildings**
- Significant acceleration of buildings renovation

**Power**
- Growing equipment industries
- Materials needs (e.g. for batteries, inverters)
The importance of battery storage and roles

• Battery storage important part of transition now to medium-term (e.g. SHS, islands, frequency response and EVs)
• Long term to integrating very high share of VRE
• In the next 3-5 years, the storage industry is positioned to scale and echo the stark growth seen in the solar PV industry.
• Incremental improvements in energy storage technologies, developments in regional regulatory and market drivers, and emerging business models are poised to make energy storage a growing and viable part of the electricity grid
• In the stationary sector, increased economic applications due to cost declines are expected for grid services as well as increased RE penetration on islands/mini-grids and off-grid
Potential locations and applications of electricity storage
IRENA’s RE costs and markets team is preparing a study to analyze and discuss stationary battery electricity options and costs

<table>
<thead>
<tr>
<th>Context</th>
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</thead>
<tbody>
<tr>
<td><strong>Existing market and technology options</strong></td>
</tr>
<tr>
<td>Latest performance and cost data (and the breakdown of costs into components) for electricity storage technologies in different geographic markets and market segments/applications.</td>
</tr>
<tr>
<td>Cost reduction potential, competitiveness of battery storage for different services and market growth in detail for electricity storage devices, focusing on batteries to 2030</td>
</tr>
</tbody>
</table>
Stationary storage today

- Source: DOE
Technology overview

Scope of analysis
Electricity Storage

Current and future cost of battery electric storage for electric power

- Detailed descriptions of 13 storage technologies including their required balance of system
- Strengths and weaknesses of each technology are highlighted, possible development paths including opportunities and threats are discussed
- One of the most comprehensive technology overviews for stationary storage systems available on the market today
- Typical system designs for 12 typical storage applications
- Excel Tool to calculate the Cost of Service of all storage technologies in different applications
Methodology

> 150 literature sources

Expert interviews

Background report
COST AND TECHNOLOGY STATUS
Small-scale: rapidly falling prices

Median prices for lithium-ion based residential storage system offers in Germany have declined roughly 60% Q4 2014 to Q1 2017.

Note: Horizontal bar shows median offer price, grey range 10th and 90th percentile.

Li-ion 60% reduction!
Current prices of different storage technologies

Current energy installations costs (USD/kWh of storage)
Reference case 2016

- High temperature ranging USD 400/kWh to USD 525/kWh
- Vanadium currently at USD 350/kWh and ZnBr at USD 900/kWh
- Current Li-ion costs ranging USD 350/kWh to USD 1050/kWh

Note: prices shown are for stationary applications and EV or specific residential applications could differ
Current prices: Pumped Hydro Storage
Potential cost evolution

Prices in 2030
USD 80 - 400/kWh

Compared to 2016
USD 190 - 1050/kWh

48-64% reduction
CHINA IS LEADING THE CHARGE
Lithium-ion megafactories in China to grow capacity 6X by 2020

Global lithium-ion battery production capacity will increase by 521% between 2016 and 2020.

<table>
<thead>
<tr>
<th></th>
<th>Capacity in 2016</th>
<th>Capacity in 2020</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>GWh</td>
<td>GWh</td>
</tr>
<tr>
<td>United States</td>
<td>1.0</td>
<td>38.0</td>
</tr>
<tr>
<td>China</td>
<td>16.4</td>
<td>107.5</td>
</tr>
<tr>
<td>Korea</td>
<td>10.5</td>
<td>23.0</td>
</tr>
<tr>
<td>Poland</td>
<td>0.0</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>27.9</strong></td>
<td><strong>173.5</strong></td>
</tr>
</tbody>
</table>

Source: http://www.visualcapitalist.com/china-leading-charge-lithium-ion-megafactories/

China's battery sector continues to be a hub for most of this growth.
Main drivers: Lithium-ion

- Differentiation between 4 different technologies
  - NMC/LMO, NCA, LFePO4 and Titanate

- International transition towards electro mobility leads to substantial scale effects (NCA NMC/LMO)
  - 70% price reduction since 2012

- > 170 GWh/year production capacities projected for 2020
  - Tesla Gigafactory / BYD / CALB / ...
  - LG Chem / Foxconn / CATL / ...

- Innovative developments
  - Mass production
  - Utilize silicon in anode
  - Durable LMO cathodes
  - 5 V electrolytes
  - Lithium-Sulphur
  - Lithium-Air
Example: Li-ion titanate

- Excellent cycle life and high-power performance
  - Used in electric busses for fast charging
  - Very low energy density compared to other lithium-ion batteries
  - High costs due to low scales

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<thead>
<tr>
<th></th>
<th>unit</th>
<th>2016</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle life</td>
<td>-</td>
<td>10k</td>
<td>12k</td>
<td>15k</td>
<td>19k</td>
<td>+ 91%</td>
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<tr>
<td>Calender life</td>
<td>years</td>
<td>15.0</td>
<td>16.9</td>
<td>19.7</td>
<td>23.0</td>
<td>+ 53%</td>
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<tr>
<td>Round-trip efficiency</td>
<td>%</td>
<td>96.0</td>
<td>96.5</td>
<td>97.1</td>
<td>97.8</td>
<td>+ 2%</td>
</tr>
<tr>
<td>Self-discharge</td>
<td>% per day</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>+ 0%</td>
</tr>
<tr>
<td>Energy installation costs</td>
<td>USD/kWh</td>
<td>1050</td>
<td>880</td>
<td>665</td>
<td>502</td>
<td>-52%</td>
</tr>
<tr>
<td>Power installation costs</td>
<td>USD/kW</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Main drivers: High-temp Batteries (NaS and ZEBRA)

- Sodium Sulfur (NaS)
  - Potential for very low cost active materials
  - Corrosion needs to be controlled

- “Low temperature” electrolytes (~150 °C) can
  - Reduce corrosion / Increase lifetime
  - Reduce thermal self-discharge
  - But low max. power, only stationary applications

- Innovative developments
  - Larger cell stacks promise cheaper production costs
  - Development of low cost corrosion resistant materials (e.g. coatings, joints, ...)

[Image of battery storage facility]
Example: High-temp NaS

- Potential for very low prices
  - Sodium and sulfur abundantly available
  - High corrosion requires expensive components

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<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>delta</th>
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<tbody>
<tr>
<td>Cycle life</td>
<td>-</td>
<td>5000</td>
<td>5614</td>
<td>6489</td>
<td>7500</td>
<td>+ 50%</td>
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<tr>
<td>Calendar life</td>
<td>years</td>
<td>17,0</td>
<td>18,8</td>
<td>21,4</td>
<td>24,3</td>
<td>+ 43%</td>
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<tr>
<td>Round-trip efficiency</td>
<td>%</td>
<td>80,0</td>
<td>81,4</td>
<td>83,2</td>
<td>85,0</td>
<td>+ 6%</td>
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<tr>
<td>Self-discharge</td>
<td>% per day</td>
<td>7,0</td>
<td>7,0</td>
<td>7,0</td>
<td>7,0</td>
<td>+ 0%</td>
</tr>
<tr>
<td>Energy installation costs</td>
<td>USD/kWh</td>
<td>525</td>
<td>436</td>
<td>326</td>
<td>243</td>
<td>-54%</td>
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<tr>
<td>Power installation costs</td>
<td>USD/kW</td>
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</table>
Tech sheets for 15 technologies
Performance

Opportunities arise also from the combined effect of higher lifetimes and lower energy installation costs
COST OF SERVICE MODELS
Cost of service calculations: Potential market segments to examine

- Grid Services
  - Enhanced Frequency Response
  - Frequency Containment Reserve
  - Frequency Restoration Reserve
  - Energy Shifting

- Behind-the-meter
  - Solar Self consumption
  - Community Storage
  - Increased Power Quality
  - Peak Shaving
  - Time-of-Ise

- Off-grid
  - Nano-grid
  - Village Electrification
  - Island Grid
Cost of service calculations: Industrial peak shaving

Application
- Industrial peak shaving
  - 200 kW rated power
  - 5 kWh nominal capacity
  - 0.6 cycles per day

Storage Technologies
- Li-Ion (LFP)
- Li-Ion (Titanate)
- Redox-Flow (ZbBr)

Results
- Cost of power per year [USD/kW]
Cost of service calculations: Industrial peak shaving
ENERGY STORAGE VALUES VARY DRAMATICALLY ACROSS LEADING STUDIES

ISO/RTO SERVICES
- Energy Arbitrage
- Frequency Regulation
- Spin / Non-Spin Reserves
- Voltage Support
- Black Start

UTILITY SERVICES
- Resource Adequacy
- Distribution Deferral
- Transmission Congestion Relief
- Transmission Deferral

CUSTOMER SERVICES
- Time-of-Use Bill Management
- Increased PV Self-Consumption
- Demand Charge Reduction
- Backup Power

Service Value [$/kW-year]

Source: Rocky Mountain Institute
# Feasibility

## Applications examples

<table>
<thead>
<tr>
<th>Grid services</th>
<th>Pumped Hydro</th>
<th>CAES</th>
<th>Flywheel</th>
<th>Lead-Acid Batteries</th>
<th>Li-Ion Batteries</th>
<th>High Temperature Flow Batteries</th>
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<tbody>
<tr>
<td>Ultra fast response</td>
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<td>Primary Reserve Control</td>
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<td>Secondary Reserve Control</td>
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<td>Minute Reserve</td>
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<td>Long-time Storage</td>
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<td>Ramping</td>
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<td>Avoid Redispacht</td>
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<td>Black start capability</td>
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<thead>
<tr>
<th>Private usage</th>
<th>Pumped Hydro</th>
<th>CAES</th>
<th>Flywheel</th>
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<th>High Temperature Flow Batteries</th>
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<td>Increase Self-Consumption</td>
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<td>Trade Energy (Spotmarket)</td>
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<td>Peak shifting</td>
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<td>Increase Power quality</td>
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<td>UPS functionality</td>
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Technically feasible, economic operation possible
Technically feasible with restrictions
Technically not feasible
Technically feasible, economically not advisable
Rapid recent cost reductions

Technology and performance improvements will continue.

Economies of scale and cost innovation key also very important.

Scale and cost reductions will open up new markets.
Timeline

Report conceptulisation is underway, consultants work being finalised

- Stakeholder meetings during Energy Storage Europe (Düsseldorf) / Intersolar and others events and meetings to present draft results
- Drafting of report: June-August 2017
- Peer review: September 2017
- Final report: October 2017
Thank you!

Questions

What areas of analysis should we focus on?

What are the questions you face domestically?

What aspects should we target for follow-up work? Self-consumption, grid-services, etc.