Original KEMA Study on Emission Benefits

- Study was conducted in 2007 and compared a flywheel to traditional technologies
  - Study highlights
    - Showed emission savings from utilization of storage
    - Study provided a simple “snapshot” of potential trends
    - Compared a flywheel to natural gas, coal, and pumped hydro systems
  - Methodology “vetted” at 2007 EESAT Conference
  - Next steps called for a “deeper dive into actual performance numbers
    - Actual simulations of specific ISO

- Today, study is still cited as the main “Emission “ Study for such applications
  - Results referenced in many cases as a secondary benefit of storage systems
    - But model simply lacked the granularity such roles require
2nd Generation Study on Emission Benefits

- Goal was to update the study using tools that have been developed since the time of the first study
  - Actual ISO territories were modeled instead of the original “snapshot” approach
  - Used emission models of actual generators instead of a “generic” plant
  - Coordinated with actual ISOs to collect the data for the study
    - CAISO model included 590 power plants and 14 control areas
    - PJM Model included 600 power plants and 19 control areas

- Results provided a more accurate assessment of the potential emissions savings to utilizing advanced storage systems vs. traditional power plants
  - Study substituted specific plants with Lithium and flywheel devices from a 25% penetration of regulation supplied up to 100% of the regulation
Tools Used for the Study

- **DNV KEMA KERMIT Model**
  - Designed to study a power systems frequency behavior over a 24 hour period
  - Able to simulate AGC signals as well as grid-scale storage
  - Defines hourly and sub-hourly generation schedules for 100s of generators

- **Emission feature of KERMIT Tools**
  - Incorporates a dynamic emissions model to estimate CO2 and NOx emissions for combustion turbines, coal plants, and combined cycle plants
  - Estimates emissions based on a generator's current output level and for utilizes ramp rates for combustion turbines

*Courtesy Dr. Jay Apt & Dr. Warren Katzenstein*
Results for PJM Territory

- Emissions reductions seen for PJM
  - Key Points about PJM
    - Largest of the ISO/RTO Territories
    - Regulation provided by a combination of coal, combined cycle, and hydro plants
    - Largest of ISO territories – regulation typically represents approximately 1% of total load

- Drivers for the market
  - Only a portion of the generators supplying services considered less efficient – hence optimal savings occurred when portion of regulation total supplied by storage
  - Really don’t have devices dedicated to regulation, typically will provide 5-20% of their output to regulation market
  - Can’t really “bump” device out of market – devices typically go back to performing in real time energy market

<table>
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<tr>
<th>Selected Day</th>
<th>CO2 Tons Base Case</th>
<th>CO2 Tons 50% Storage</th>
<th>Difference</th>
<th>Estimated Month Total</th>
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<td>1395</td>
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<td><strong>Total Year</strong></td>
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<td><strong>15567</strong></td>
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Results for CAISO Study

- Results less conclusive
  - Simulations were run over 6 days throughout the year – model was not able to pick up trends or patterns of reduction or increases
  - Why? Regulation market made up of pumped hydro, combustion turbines, combined cycle plants
  - Follows similar trends to PJM where generators contribute partial amounts of nameplate capacity to regulation

- Using storage to replace Spinning Reserve
  - Examined as a potential area of benefit
  - Four cases examined
    - Hypothetical 100 MW of spinning reserve where it is replaced by 20 MW of storage and 80 MW of traditional generation

<table>
<thead>
<tr>
<th>Case</th>
<th>CO2 (ton) Before</th>
<th>CO2 (ton) After</th>
<th>NOx (lb) Before</th>
<th>NOx (lb) After</th>
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Questions?