Hybrid Power Plants: Status of Installed and Proposed Projects

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Scope includes **co-located** plants that pair two or more generators and/or that pair generation with storage at a single point of interconnection, and also **full hybrids** that feature co-location and co-control; ‘**virtual’ hybrids** are excluded, as are **smaller** (often behind-the-meter) projects not otherwise visible in data sources used here.
Existing Hybrid Projects: Installed by end of 2019
Methods and Data Source

- Form **EIA-860 2019 early release**
  - Generator specific information for power plants with **>1 MW combined** capacity
  - Very limited amount of spot checking for corrections to EIA data
- Hybrids identified by having the **same EIA ID**
  - **Suggests co-location of generators** at one plant / point of interconnection, but not necessarily co-controlled generators
  - Virtual hybrids cannot be identified; smaller plants excluded
- Challenges and Limitations:
  - Difficult to separate behind-the-meter/micro-grid resources from front of the meter resources
  - **EIA ID does not identify all hybrids or co-located plants** as some co-located plants could have different IDs
Hybrid / co-located projects of various configurations exist as of the end of 2019, but market remains limited in overall size.

125 projects, 13.4 GW of generating capacity, 0.9 GW storage capacity

<table>
<thead>
<tr>
<th>Installed at end of 2019</th>
<th># projects</th>
<th>Gen 1 (MW)</th>
<th>Gen 2 (MW)</th>
<th>Gen 3 (MW)</th>
<th>Total Gen (MW)</th>
<th>Storage capacity (MW)</th>
<th>Storage energy (MWh)</th>
<th>Storage: generator ratio</th>
<th>Duration (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind+Storage</td>
<td>13</td>
<td>1,290</td>
<td>0</td>
<td>0</td>
<td>1,290</td>
<td>184</td>
<td>109</td>
<td>14%</td>
<td>0.6</td>
</tr>
<tr>
<td>Wind+PV+Storage</td>
<td>2</td>
<td>216</td>
<td>21</td>
<td>0</td>
<td>237</td>
<td>34</td>
<td>15</td>
<td>15%</td>
<td>0.4</td>
</tr>
<tr>
<td>Wind+Fossil+Storage</td>
<td>1</td>
<td>5</td>
<td>12</td>
<td>0</td>
<td>17</td>
<td>1</td>
<td>1</td>
<td>7%</td>
<td>0.8</td>
</tr>
<tr>
<td>Wind+PV+Fossil+Storage</td>
<td>1</td>
<td>0.1</td>
<td>0.1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>25%</td>
<td>1.7</td>
</tr>
<tr>
<td>Wind+PV</td>
<td>6</td>
<td>535</td>
<td>212</td>
<td>0</td>
<td>747</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>n/a</td>
</tr>
<tr>
<td>Wind+PV+Fossil</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>98</td>
<td>106</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>n/a</td>
</tr>
<tr>
<td>Wind+Fossil</td>
<td>8</td>
<td>27</td>
<td>79</td>
<td>0</td>
<td>106</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>n/a</td>
</tr>
<tr>
<td>PV+Storage</td>
<td>40</td>
<td>882</td>
<td>0</td>
<td>0</td>
<td>882</td>
<td>169</td>
<td>446</td>
<td>19%</td>
<td>2.6</td>
</tr>
<tr>
<td>PV+Fossil</td>
<td>26</td>
<td>77</td>
<td>6,876</td>
<td>0</td>
<td>6,953</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>n/a</td>
</tr>
<tr>
<td>PV+Fossil+Storage</td>
<td>3</td>
<td>9</td>
<td>10</td>
<td>0</td>
<td>20</td>
<td>5</td>
<td>9</td>
<td>24%</td>
<td>1.9</td>
</tr>
<tr>
<td>PV+Biomass</td>
<td>3</td>
<td>4</td>
<td>15</td>
<td>0</td>
<td>19</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>n/a</td>
</tr>
<tr>
<td>PV+Geothermal</td>
<td>2</td>
<td>18</td>
<td>85</td>
<td>0</td>
<td>103</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>n/a</td>
</tr>
<tr>
<td>PV+Geothermal+CSP</td>
<td>1</td>
<td>22</td>
<td>47</td>
<td>2</td>
<td>71</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>n/a</td>
</tr>
<tr>
<td>CSP+Storage</td>
<td>2</td>
<td>390</td>
<td>0</td>
<td>0</td>
<td>390</td>
<td>390</td>
<td>2,780</td>
<td>100%</td>
<td>7.1</td>
</tr>
<tr>
<td>Fossil+Storage</td>
<td>10</td>
<td>2,414</td>
<td>0</td>
<td>0</td>
<td>2,414</td>
<td>91</td>
<td>84</td>
<td>4%</td>
<td>0.9</td>
</tr>
<tr>
<td>Hydro+Storage</td>
<td>4</td>
<td>71</td>
<td>0</td>
<td>0</td>
<td>71</td>
<td>12</td>
<td>11</td>
<td>17%</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Sources: EIA 860 2019 Early Release, Berkeley Lab

Note: **Pumped hydro** is not considered a hybrid resource for the purpose of this compilation. The hydro+storage plants noted in the table pair hydropower with batteries.
Hybrid / co-located projects of various configurations exist as of the end of 2019, but market remains limited in overall size (2)

### Wind Hybrids / Co-located Projects
- Wind+Storage dominates configurations: 13 projects, 1,290 MW wind, 184 MW storage
  - Small storage:generator ratios (14%) and storage durations (0.6 hrs) on average, built for AS markets
- Wind+PV (535 MW wind) and Wind+PV+Storage (216 MW wind) also present
- Configurations that include fossil involve minor amounts of wind

### PV Hybrids / Co-located Projects
- PV+Storage dominates configurations: 40 projects, 882 MW solar, 169 MW storage
  - Small storage:generator ratios (19%), but longer storage durations (2.6 hrs) on average
- PV+Fossil is common (26 projects) but involves minor amount of PV (77 MW) added to fossil units (6,876 MW, including 3 coal plants totaling 5 GW) at point of interconnection
- Other configurations w/ wind, fossil, biomass, geothermal, CSP involve small amount of PV

### Fossil Hybrids / Co-located Projects
- Fossil+PV is most common: small amount of PV added to larger fossil units (6,876 MW)
- Fossil+Storage also relatively common (10 projects, 2,414 MW fossil, 91 MW storage)
  - Small storage:generator ratios (4%) and storage durations (0.9 hrs) on average, built for AS markets

### CSP, Geothermal, Hydropower, Biomass Hybrids / Co-located Projects
- Multiple configurations, with CSP+Storage involving the most capacity
Comparing the frequency and design of a subset of the various hybrid / co-located project configurations: end of 2019

<table>
<thead>
<tr>
<th># projects</th>
<th>Total capacity (MW)</th>
<th>Storage ratio</th>
<th>Duration (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>PV+Storage</td>
<td>40</td>
<td>881.6</td>
<td>169.1</td>
</tr>
<tr>
<td>Wind+Storage</td>
<td>13</td>
<td>1,289.9</td>
<td>183.6</td>
</tr>
<tr>
<td>Wind+PV+Storage</td>
<td>2</td>
<td>215.8</td>
<td>20.7</td>
</tr>
<tr>
<td>Fossil+Storage</td>
<td>10</td>
<td>2,413.6</td>
<td>91.0</td>
</tr>
<tr>
<td>Wind+PV</td>
<td>6</td>
<td>535.3</td>
<td>211.5</td>
</tr>
</tbody>
</table>

Notes: Not included in the figure are 54 other hybrid / co-located projects with other configurations; details on those projects are provided in the table on the previous slide. **Storage ratio** defined as total storage capacity divided by total generation capacity within a type. **Duration** defined as total MWh of storage divided by total MW of storage within a type.

Sources: EIA 860 2019 Early Release, Berkeley Lab
PV hybrid / co-located projects of various configurations as of the end of 2019, and over time

Online PV Hybrid / Co-located Projects

Growth in PV Hybrid / Co-located Projects over Time

depicts amount of PV and other types of generation and storage being paired with PV, over time

Note: PV+fossil plants involve minor amount of PV added to larger fossil units at the point of interconnection: thus, the fossil category dominates this figure

Note: The larger PV+storage projects in California are in LADWP’s service territory, not CAISO

Sources: EIA 860 2019 Early Release, Berkeley Lab
Wind hybrid / co-located projects of various configurations as of the end of 2019, and over time

Online Wind Hybrid / Co-located Projects

Growth in Wind Hybrid / Co-located Projects over Time

depicts amount of wind and other types of generation and storage being paired with wind, over time

Sources: EIA 860 2019 Early Release, Berkeley Lab
Generator + storage hybrid / co-located projects at end of 2019, compared to subset of standalone storage technologies

- Wind+storage plants located primarily in ERCOT and PJM so far
- PV+storage plants located primarily in non-ISO West, ERCOT, and Southeast
- Fossil+storage plants located primarily in MISO and ISO-NE
- Standalone storage (ex. pumped hydro) largely in PJM, CAISO, Southeast

Sources: EIA 860 2019 Early Release, Berkeley Lab
Standalone storage (even excluding pumped hydro) capacity exceeds the storage capacity included in existing hybrids

- Standalone storage capacity (battery, flywheel and CAES, excluding pumped hydro) is greatest in PJM, CAISO, Southeast
- Standalone storage capacity exceeds storage capacity included in wind+storage, PV+storage, and fossil+storage hybrids
- Storage capacity included in hybrids is located roughly in proportion to where the hybrid plants are located

Sources: EIA 860 2019 Early Release, Berkeley Lab
Longer-term Pipeline:
Interconnection Queues at end of 2019
Methods and Data Sources

- Data from **generator interconnection queues** for 7 ISOs and 30 utilities, representing ~80% of all U.S. electricity load
  - Projects that connect to the bulk power system: not behind-the-meter or virtual
  - Includes all projects in queues through the end of 2019
  - Filtered to include only “active” projects: removed “online,” “withdrawn,” “suspended”

- Hybrid / co-located projects identified via either of these two methods:
  - “Generator Type” field includes **multiple types for a single queue entry** (row)
  - Two or more queue entries (of different gen. types) that share the **same point of interconnection** and sponsor, queue date, ID number, and/or COD
    - Emphasis was placed on identification of wind+storage and solar+storage
    - Other hybrid configurations are likely undercounted

- Storage capacity for hybrids (i.e., broken out from generator capacity) was **only available for 4 of 7 ISOs**, and not collected for the utilities
  - Available for: CAISO, ERCOT, SPP, and NYISO

- Note that being in an interconnection queue does not guarantee ultimate construction: majority of plants are not subsequently built
Interconnection queues indicate that commercial interest in solar, wind and storage has grown, including via hybridization.

Source: Berkeley Lab review of 37 ISO and utility interconnection queues

Note: Not all of this capacity will be built.
Interest in hybrid plants has increased: 28% of solar proposed as hybrids (102 GW), 5% of wind proposed as hybrids (11 GW)

Notes: (1) Not all of this capacity will be built; (2) Hybrid plants involving multiple generator types (e.g., wind+PV+storage, wind+PV) show up in all generator categories, presuming the capacity is known for each type.

Source: Berkeley Lab review of interconnection queues

Solar+Storage and Wind+Storage configurations are more common than other hybrid types¹

¹ Emphasis was placed on identification of wind+storage and solar+storage: other hybrid configurations are likely undercounted.
Hybrids comprise a sizable fraction of all proposed solar plants in multiple regions; proposed wind hybrids dominated by CAISO

<table>
<thead>
<tr>
<th>Region</th>
<th>Wind</th>
<th>Solar</th>
<th>Nat. Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAISO</td>
<td>50%</td>
<td>67%</td>
<td>0%</td>
</tr>
<tr>
<td>ERCOT</td>
<td>3%</td>
<td>13%</td>
<td>0%</td>
</tr>
<tr>
<td>SPP</td>
<td>1%</td>
<td>22%</td>
<td>0%</td>
</tr>
<tr>
<td>MISO</td>
<td>2%</td>
<td>17%</td>
<td>0%</td>
</tr>
<tr>
<td>PJM</td>
<td>0%</td>
<td>17%</td>
<td>1%</td>
</tr>
<tr>
<td>NYISO</td>
<td>1%</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>ISO-NE</td>
<td>6%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>West (non-ISO)</td>
<td>6%</td>
<td>50%</td>
<td>0%</td>
</tr>
<tr>
<td>Southeast (non-ISO)</td>
<td>0%</td>
<td>6%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>4.8%</strong></td>
<td><strong>27.7%</strong></td>
<td><strong>0.6%</strong></td>
</tr>
</tbody>
</table>

Source: Berkeley Lab review of interconnection queues

Note: Not all of this capacity will be built

- **Solar** hybridization relative to total amount of solar in each queue is highest in CAISO (67%) and non-ISO West (50%), and is above 10% in PJM, MISO, ERCOT

- **Wind** hybridization relative to total amount of wind in each queue is highest in CAISO (50%), and is less than 7% in all other regions
Solar+storage is dominant hybrid type in queues, wind+storage is much less common; CAISO & West of greatest interest so far

Average storage:generation capacity ratio for solar+storage (66%) is higher than for wind+storage (27%), in subset of ISO queues; these are both much higher than for existing hybrid plants shown earlier

<table>
<thead>
<tr>
<th>Region</th>
<th>Wind+Storage</th>
<th>Solar+Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAISO</td>
<td>25%</td>
<td>78%</td>
</tr>
<tr>
<td>ERCOT</td>
<td>54%</td>
<td>38%</td>
</tr>
<tr>
<td>SPP</td>
<td>23%</td>
<td>38%</td>
</tr>
<tr>
<td>NYISO</td>
<td>7%</td>
<td>49%</td>
</tr>
<tr>
<td><strong>Combined</strong></td>
<td><strong>27%</strong></td>
<td><strong>66%</strong></td>
</tr>
</tbody>
</table>

*Source: Berkeley Lab review of interconnection queues*

*Note: Not all of this capacity will be built*
Wind+storage, PV+storage, and fossil+storage plants all exist in limited quantities as of end of 2019.

Many other configurations are present, but in most cases (except fossil+PV) these are less common.

Storage:generation ratios and storage durations tend to be higher for installed PV+storage plants.

Standalone storage capacity (even excluding pumped hydro) exceeds storage in existing hybrids.

Forward-looking interest is dominated by solar+storage plants: ~10x more than wind+storage.

CAISO and non-ISO west are the two regions of greatest apparent commercial interest so far.

Data availability for hybrid /co-located plants is limited, especially given the wide variety of plant configurations. Even standardized definitions for what constitutes a hybrid is lacking. Market tracking challenges follow. Nonetheless, some basic conclusions from this synthesis include:
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