Over 31% of U.S. hydropower fleet’s capacity has very limited flexibility

**Run-of-river + canal/conduit:**
- Have little to no active water storage (in = out)
- Without storage cannot provide peaking power or essential reliability services
- Limited revenue streams

**By plants:**
- 72%

**By capacity:**
- 31%

The relative value of services in the electrical grid is increasing

- The cost of energy is decreasing
- The relative value of services is increasing

Increasing hydropower’s flexibility through “virtual reservoirs”
Hybrid energy storage systems: utilizing strengths of multiple technologies

- **Supercapacitors**: Less expensive on a capacity basis, tolerant to cycling patterns, don’t degrade with cycling
- **Batteries**: Less expensive on an energy basis, degradation depends on use
- **Flywheels**: More expensive, but tolerant to environmental conditions and cycling patterns, don’t degrade much with cycling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Li-Ion battery</th>
<th>Flywheel</th>
<th>Supercapacitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total project cost ($/kW)</td>
<td>1,876 (1,446)</td>
<td>2,880</td>
<td>931 (833)</td>
</tr>
<tr>
<td>Total project cost ($/kWh)</td>
<td>469 (362)</td>
<td>11,520</td>
<td>74,480 (66,640)</td>
</tr>
<tr>
<td>Round-trip efficiency (%)</td>
<td>86</td>
<td>86</td>
<td>92</td>
</tr>
<tr>
<td>Response Time (s)</td>
<td>1</td>
<td>0.25</td>
<td>0.016</td>
</tr>
<tr>
<td>Cycles</td>
<td>3,500</td>
<td>200,000</td>
<td>1 million</td>
</tr>
</tbody>
</table>

Balducci, PNNL, 2019, in-press
Energy storage can boost power output quickly, supporting ROR and reservoir-based hydropower.
Siemens Smart Energy Box (SEB)
- Receives generation requests
- Tracks state of each device
- Optimizes utilization of each device and sends control signals
Case study on revenue potential: Idaho Falls Power

- IFP has four single-unit ROR hydropower plants:
  - Upper: 7.1 MW
  - City: 7.3 MW
  - Lower: 6.9 MW
  - Gem: 22.7 MW

- CHEERS model by Argonne optimizes market participation
  ((Conventional Hydropower Energy and Environmental Systems))

- Assumed range of market conditions based on CAISO
Revenue increases due to energy storage
Battery storage: +12.2% to +15.8%
Flywheel: +12.0% to +16.3%
Enabling ROR plants to provide distribution-level black starts

1. Excite system; set controls and protections to black start mode
2. Add load in steps; as load added, discharge supercapacitors and ramp hydropower to stabilize circuit
3. Charge supercapacitors
4. Repeat until hydropower plant at desired generation state

Preparing for field demonstration with Idaho Falls Power (spring 2020)
Integrated hydropower and energy storage being built in some markets

Deployments of integrated hydropower and energy storage (by market/grid)

- **Microgrid**
  - Cordova Electric Cooperative
  - Kodiak Electric Association
  - Ensure grid stability
  - Reduce diesel consumption
  - Must provide all grid needs

- **Traditional (provides balancing)**
  - Economically meet reliability standards
  - Integrate qualifying variable renewables
  - Able to contract with other asset owners or operators

- **Restructured (sells into market)**
  - American Electric Power
  - Fortum
  - Increase revenue through providing ancillary services
  - Not responsible for balancing
Next steps: moving from lab to real-world

✓ Distribution-level black start: Idaho Falls Power, Spring 2020
  ○ Other integrated hydropower and energy storage use cases: ?

Digital simulation
- Use digital model of system (either component-level or aggregated)
- Adequate for testing overall system characteristics

Hardware testing
- Integrate digital and physical hardware components
- Most accurate method for lab-based assessment and validation

Field demonstration
- Most realistic
- Necessary to ensure system reliability

Project risk

Cost of evaluation
“Virtual reservoirs”: increasing the menu of services that can be provided by run-of-river hydropower

Send inquiries to:
waterpower@INL.gov