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# Battery Energy Storage System (BESS): A Cost/Benefit Analysis for a PV power station.

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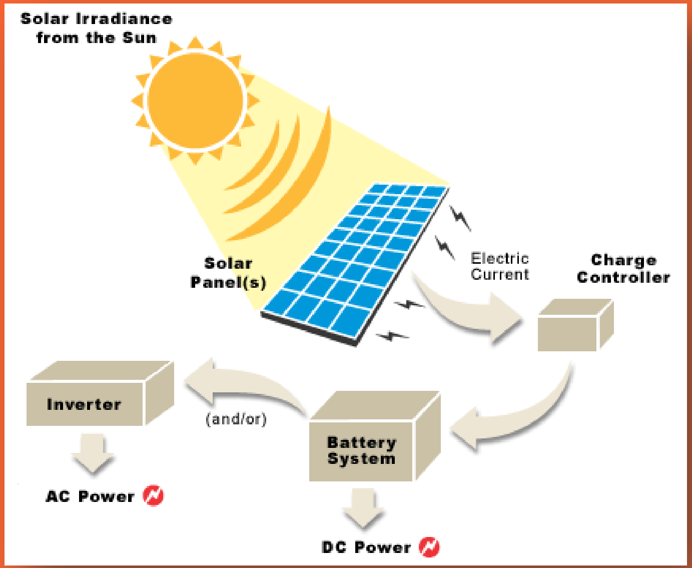
# Cost/Benefit Analysis: Step by Step

- The cases used for distribution system simulations:
  - IEEE 13 Node Test Feeder case
  - IEEE 34 Node Test Feeder case
- BESS sizing:
  - System capabilities
  - Applications intended to be supported
- BESS placement:
  - Power losses minimization
  - Power line voltage limits
- Calculating the cost and revenue generated by the applications for a BESS (Li-Ion)
- Evaluating the investment and building a business case



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# Cost Analysis: BESS Applications

| Category 1 — Electric Supply |
|---|
| 1. Electric Energy Time-shift |
| 2. Electric Supply Capacity |
| **Category 2 — Ancillary Services** |
| 3. Load Following |
| 4. Area Regulation |
| 5. Electric Supply Reserve Capacity |
| 6. Voltage Support |
| **Category 3 — Grid System** |
| 7. Transmission Support |
| 8. Transmission Congestion Relief |
| 9. Transmission & Distribution (T&D) Upgrade Deferral |
| 10. Substation On-site Power |
| **Category 4 — End User/Utility Customer** |
| 11. Time-of-use (TOU) Energy Cost Management |
| 12. Demand Charge Management |
| 13. Electric Service Reliability |
| 14. Electric Service Power Quality |
| **Category 5 — Renewables Integration** |
| 15. Renewables Energy Time-shift |
| 16. Renewables Capacity Firming |
| 17. Wind Generation Grid Integration |

Energy Storage for the Electricity Grid Benefits and Market Potential Assessment by Sandia NL 2010

Five Categories of Energy Storage Applications

# Cost Analysis: Applications Synergies Matrix

● Excellent ◐ Good ◎ Fair ○ Poor ⊗ Incompatible

| Application | Electric Energy Time-shift | Electric Supply Capacity | Load Following | Area Regulation | Electric Supply Reserve Capacity | Voltage Support[1] | Transmission Congestion Relief[1] | T&D Upgrade Deferral[1] | Time-of-Use Energy Cost Management[1] | Demand Charge Management[1] | Electric Service Reliability[1] | Electric Service Power Quality[1] | Renewables Energy Time-shift | Renewables Capacity Firming | Wind Generation Grid Integration |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric Energy Time-shift | | ● | ◐ | ◎* | ◐ | ● | ●† | ●† | ⊗ | ⊗ | ⊗ | ⊗ | ◐ | ◐ | ◎ |
| Electric Supply Capacity | ● | | ◐* | ◎* | ◐* | ● | ◐† | ●† | ⊗ | ⊗ | ⊗ | ⊗ | ◎X* | ◎X* | ⊗ |
| Load Following | ◐ | ◐* | | ◎* | ◐* | ◐ | ◎X | ◐X* | ◎*‡ | ◎*‡ | ⊗ | ⊗ | ◎ | ⊗ | ⊗ |
| Area Regulation | ◎* | ◎* | ◎* | | ◎* | ⊗ | ◎X* | ⊗ | ⊗ | ⊗ | ⊗ | ⊗ | ○ | ○ | ⊗ |
| Electric Supply Reserve Capacity | ◐ | ◐* | ◐* | ◎* | | ● | ◎* | ◐* | ◐*‡ | ◐*‡ | ⊗ | ⊗ | ◎* | ◎* | ○* |
| Voltage Support[1] | ● | ● | ◐ | ⊗ | ● | | ◐ | ● | ◐‡ | ◐‡ | ◐‡ | ◐‡ | ◐#‡ | ◐#‡ | ⊗ |
| Transmission Congestion Relief[1] | ●† | ◐† | ◎X | ◎X* | ◎* | ◐ | | ◐X† | ◐† | ◐† | ○ | ⊗ | ◐# | ◐† | ⊗ |
| T&D Upgrade Deferral[1] | ●† | ●† | ◐X* | ⊗ | ◐* | ● | ◐X† | | ◐† | ◐† | ○ | ⊗ | ◐# | ◐† | ⊗ |
| Time-of-Use Energy Cost Management[1] | ⊗ | ⊗ | ◎*‡ | ⊗ | ◐*‡ | ◐‡ | ◐† | ◐† | | ●† | ● | ● | ◐# | ◐†# | ⊗ |
| Demand Charge Management[1] | ⊗ | ⊗ | ◎*‡ | ⊗ | ◐*‡ | ◐‡ | ◐† | ◐† | ●† | | ● | ● | ◐# | ●†# | ⊗ |
| Electric Service Reliability[1] | ⊗ | ⊗ | ⊗ | ⊗ | ⊗ | ◐‡ | ○ | ○ | ● | ● | | ● | ◐# | ◐# | ⊗ |
| Electric Service Power Quality[1] | ⊗ | ⊗ | ⊗ | ⊗ | ⊗ | ◐‡ | ⊗ | ⊗ | ● | ● | ● | | ⊗ | ⊗ | ⊗ |
| Renewables Energy Time-shift | ◐ | ◎X* | ◎ | ○ | ◎* | ◐#‡ | ◐# | ◐# | ◐# | ◐# | ◐# | ⊗ | | ● | ◎X |
| Renewables Capacity Firming | ◐ | ◎X* | ⊗ | ○ | ◎* | ◐#‡ | ◐† | ◐† | ◐†# | ●†# | ◐# | ⊗ | ● | | ◎X |
| Wind Generation Grid Integration | ◎ | ⊗ | ⊗ | ⊗ | ○* | ⊗ | ⊗ | ⊗ | ⊗ | ⊗ | ⊗ | ⊗ | ◎X | ◎X | |

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# Cost Analysis: Application Power Ratings (kWs - MWs)

| # | Type | Storage Power Low | Storage Power High | Storage Power Note |
|---|---|---|---|---|
| 1 | Electric Energy Time-shift ★ | 1 MW | 500 MW | Low per ISO transaction min. (Can aggregate smaller capacity.) High = combined cycle gen. |
| 2 | Electric Supply Capacity | 1 MW | 500 MW | Same as above. |
| 3 | Load Following ★ | 1 MW | 500 MW | Same as above. |
| 4 | Area Regulation | 1 MW | 40 MW | Low per ISO transaction min. Max is 50% of estimated CA technical potential of 80 MW. |
| 5 | Electric Supply Reserve Capacity | 1 MW | 500 MW | Low per ISO transaction min. (Can aggregate smaller capacity.) High = combined cycle gen. |
| 6 | Voltage Support | 1 MW | 10 MW | Assume distributed deployment, to serve Voltage support needs locally. |
| 7 | Transmission Support | 10 MW | 100 MW | Low value is for substransmission. |
| 8 | Transmission Congestion Relief | 1 MW | 100 MW | Low per ISO transaction min. (Can aggregate smaller capacity.) High = 20% of high capacity transmission. |
| 9.1 | T&D Upgrade Deferral 50th percentile | 250 kW | 5 MW | Low = smallest likely, High = high end for distribution & subtransmission. |
| 9.2 | T&D Upgrade Deferral 90th percentile | 250 kW | 2 MW | Same as above. |
| 10 | Substation On-site Power | 1.5 kW | 5 kW | Per EPRI/DOE Substation Battery Survey. |
| 11 | Time-of-use Energy Cost Management | 1 kW | 1 MW | Residential to medium sized commercial/industrial users. |
| 12 | Demand Charge Management | 50 kW | 10 MW | Small commercial to large commercial/industrial users. |
| 13 | Electric Service Reliability | 0.2 kW | 10 MW | Low = Under desk UPS. High = facility-wide for commercial/industrial users. |
| 14 | Electric Service Power Quality | 0.2 kW | 10 MW | Same as above. |
| 15 | Renewables Energy Time-shift | 1 kW | 500 MW | Low = small residential PV. High = "bulk" renewable energy fueled generation. |
| 16 | Renewables Capacity Firming ★ | 1 kW | 500 MW | Same as above. |
| 17.1 | Wind Generation Grid Integration, Short Duration ★ | 0.2 kW | 500 MW | Low = small residential turbine. High = larged wind farm boundary. |
| 17.2 | Wind Generation Grid Integration, Long Duration | 0.2 kW | 500 MW | Same as above. |

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# Cost Analysis: Application Duration Ratings (sec - hrs)

| # | Type | Discharge Duration* Low | High | Note |
|---|---|---|---|---|
| 1 | Electric Energy Time-shift ★ | 2 | 8 | Depends on energy price differential, storage efficiency, and storage variable operating cost. |
| 2 | Electric Supply Capacity | 4 | 6 | Peak demand hours |
| 3 | Load Following ★ | 2 | 4 | Assume: 1 hour of discharge duration provides approximately 2 hours of load following. |
| 4 | Area Regulation | 15 min. | 30 min. | Based on demonstration of Beacon Flywheel. |
| 5 | Electric Supply Reserve Capacity | 1 | 2 | Allow time for generation-based reserves to come on-line. |
| 6 | Voltage Support | 15 min. | 1 | Time needed for a) system stabilization or b) orderly load shedding. |
| 7 | Transmission Support | 2 sec. | 5 sec. | Per EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications.[17] |
| 8 | Transmission Congestion Relief | 3 | 6 | Peak demand hours. Low value is for "peaky" loads, high value is for "flatter" load profiles. |
| 9.1 | T&D Upgrade Deferral 50th percentile | 3 | 6 | Same as Above |
| 9.2 | T&D Upgrade Deferral 90th percentile | 3 | 6 | Same as Above |
| 10 | Substation On-site Power | 8 | 16 | Per EPRI/DOE Substation Battery Survey. |
| 11 | Time-of-use Energy Cost Management | 4 | 6 | Peak demand hours. |
| 12 | Demand Charge Management | 5 | 11 | Maximum daily demand charge hours, per utility tariff. |
| 13 | Electric Service Reliability | 5 min. | 1 | Time needed for a) shorter duration outages or b) orderly load shutdown. |
| 14 | Electric Service Power Quality | 10 sec. | 1 min. | Time needed for events ridethrough depends on the type of PQ challenges addressed. |
| 15 | Renewables Energy Time-shift ★ | 3 | 5 | Depends on energy cost/price differential and storage efficiency and variable operating cost. |
| 16 | Renewables Capacity Firming ★ | 2 | 4 | Low & high values for Renewable Gen./Peak Load correlation (>6 hours) of 85% & 50%. |
| 17.1 | Wind Generation Grid Integration, Short Duration | 10 sec. | 15 min. | For a) Power Quality (depends on type of challenge addressed) and b) Wind Intermittency. |
| 17.2 | Wind Generation Grid Integration, Long Duration | 1 | 6 | Backup, Time Shift, Congestion Relief. |

*Hours unless indicated otherwise. Min. = minutes. Sec. = Seconds.

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# Cost Analysis: Cost Breakdown

1. Capital cost or plant financial carrying charges
   a. Storage System footprint and space requirements (Energy and Power density).
   b. BESS (batteries, power converters, etc.)
   c. Facility infrastructure (communications and control, environmental control, grid interconnection, etc.)

2. Total operating cost:
   a. Cost for charging the system
   b. Labor associated with plant operation
   c. Plant maintenance
   d. Replacement and repair cost
   e. Decommissioning and disposal cost

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# Cost Analysis: BESS - Capital Costs

- The cost of the storage unit:
  $Cost_{storage}$ *($)* = Unit $Cost_{storage}$*($/kWh)* * E*(kWh)*

- All systems have some inefficiency factor *(η)* hence:
  $Cost_{storage}$*($)* = Unit $Cost_{storage}$*($/kWh)* * (E*(kWh)* / η)

- The cost of the Power Conversion System is:
  $Cost_{pcs}$ *($)* = Unit $Cost_{pcs}$*($/kW)* * P*(kW)*

- The Total Cost is:
  $Cost_{total}$*($)* = $Cost_{pcs}$*($)* + $Cost_{storage}$*($)*

- When, the unit costs of the subsystems are known, and the storage capacity in *kW* is known, it is possible to rewrite the total cost in terms of the power rating:
  $Cost_{system}$ *($/kW)* = $Cost_{total}$*($)* / P*(kW)*

Energy Storage Systems Cost Update by Sandia NL 2011

# Cost Analysis: Utilizing Used Li-Ion Batteries.

- A **new** 15 kWh battery pack currently costs **$990/kWh to $1,220/kWh** (projected cost: 360/kWh to $440/kWh by 2020).

- The expectation is that the **Li-Ion** (EV) batteries will be **replaced** with a fresh battery pack once their efficiency (energy or peak power) **decreases to 80%**. Based on various forecasts for market penetration of PHEVs and EVs over the **next 10 years**, a large number of PHEVs and EVs will be approaching this 80% efficiency level by 2020. These batteries can be **recycled** or used in other less demanding applications for the rest of their useful life provided a business case can be made for their secondary use.

- The **minimum goal** for a selling price for a Used Li-Ion Batteries is less than **$150/kWh** for 25,000 units at 40 kWh.

Economic Analysis of Deploying Used Batteries in Power Systems by Oak Ridge NL 2011

# Benefit Analysis: Revenue Generating Applications

1. Electric Energy Time-Shift
2. Load Following
3. Renewables Energy Time-Shift
4. Renewables Capacity Firming

# Benefit Analysis: Electric Energy Time-Shift

- Basic concept: *Buy low / Sell high*
- Key elements:
  - Hourly prices
  - Round trip efficiency
  - Discharge duration
- For about 900hrs/year the price is $100/MWhr* (peak time)
- For about (8760-900)=7860hrs/year the price is $50~$60/MWhr* (off-peak time)

Decision making process: If the cost for wear on the storage system, plus the cost for charging energy, plus the cost to make up for storage losses exceeds the expected benefit, then the transaction is not made.

✓ The generic benefit estimate for Electric Energy Time-Shift ranges from $400/kW to $700/kW (over 10 years).

*****Wholesale Electricity Price Forecast data provided by Joel Klein, California Energy Commission 2008
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## Benefit Analysis: Renewables Energy Time-Shift

- Similar concept Electric Energy Time-Shift but with emphasis on the renewable energy source.
- Instead of selling off-peak energy in real-time (when generated), that energy is stored and used at a later time when energy prices are high.
  - ✓ Peak time 12:00 pm – 5:00 pm
- Storing low-priced energy from the grid *and* directly from renewable energy generation means that there is more energy output from the renewable energy plus storage system than could be delivered if only energy from renewable energy generation is stored.

✓ The generic benefit estimate for Renewables Energy Time-Shift ranges from $233/kW to $389/kW (over 10 years).

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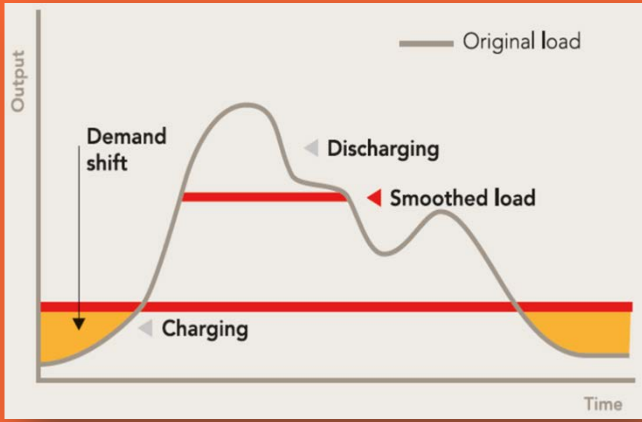
# Benefit Analysis: Load Following

- The benefit consists of two possible scenarios:
  - Marginal cost: Cost for fuel and variable maintenance
    - Low end cost $20/MW per hour (hydroelectric plant)
    - High end cost $50/MW per hour (combined cycle generation)
  - Capacity cost: Cost for additional generation capacity
    - A simple cycle combustion turbine costs $60/kW-year
    - A combined cycle plant costs $120/kW-year

✓ The generic benefit estimate for Load Following ranges from $359/kW to $710/kW (over 10 years).

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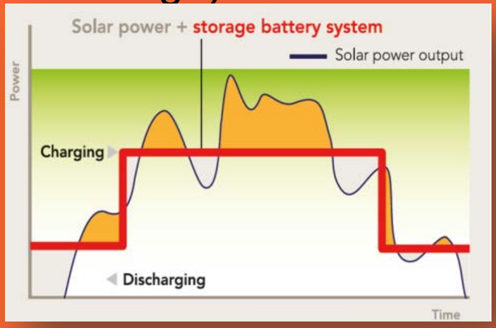
# Benefit Analysis: Renewables Capacity Firming

- A well-optimized, solar generation facility can have a 0.80 capacity credit.
- Whereas another solar generation facility might be firmed with a capacity credit of 0.40 (*i.e.,* distributed, flat panel PV modules with a suboptimal and fixed orientation, regular dust accumulation, shading by surroundings, high ambient temperatures, high level of cloudiness, etc.).
- Adding storage to distributed fixed-orientation PV is assumed to increase the capacity credit from 0.40 to 1.0.
- The renewables capacity firming benefit estimated for adding storage to renewable energy generation is incremental. Consequently, the financial merits of adding storage to renewables generation, the incremental benefit is compared to incremental cost (to add storage).

✓ The generic benefit estimate for Renewables Capacity Firming ranges from $709/kW to $915/kW (over 10 years).

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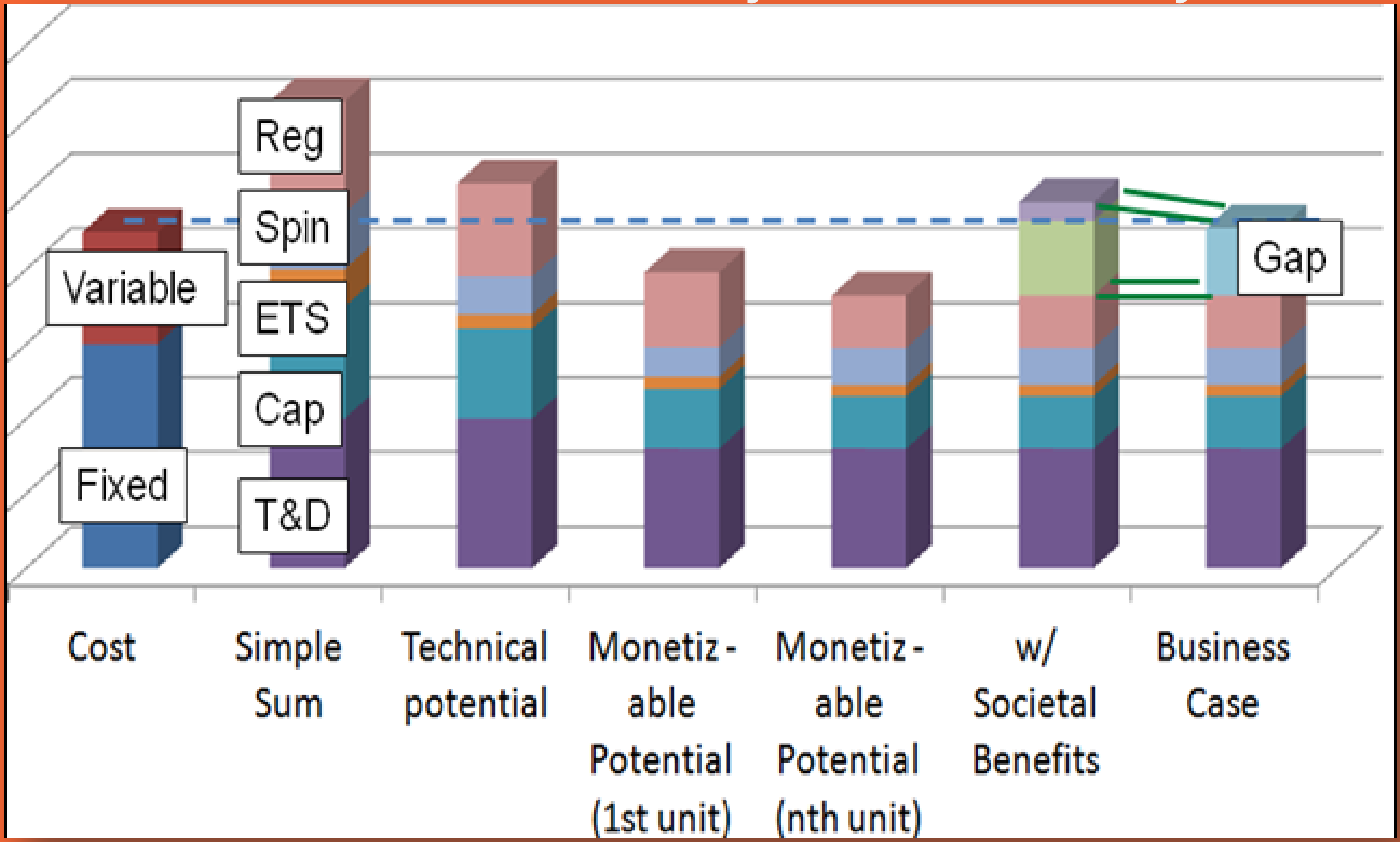
# Cost/Benefit Analysis: Summary




- Phase 1: Define Grid Services
- Phase 2: Identify Feasible Use Cases
- Phase 3: Understand Grid Impacts
- Phase 4: Form Business Cases

Cost-Effectiveness of Energy Storage in California by EPRI 2013

# Future Work

- Apply different methods to evaluate an investment in BESS:
  - Rate of Return
  - Payback time
  - Net Present Value
  - SWOT analysis
- Evaluate a system with and without an BESS (comparative study)
- Hardware testing of a BESS (eGRID)