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NATIONAL RENEWABLE ENERGY LABORATORY

# Energy Storage Management for VG Integration

*Photo by NREL/PIX 19498*

## UWIG FALL TECHNIICAL WORKSHOP


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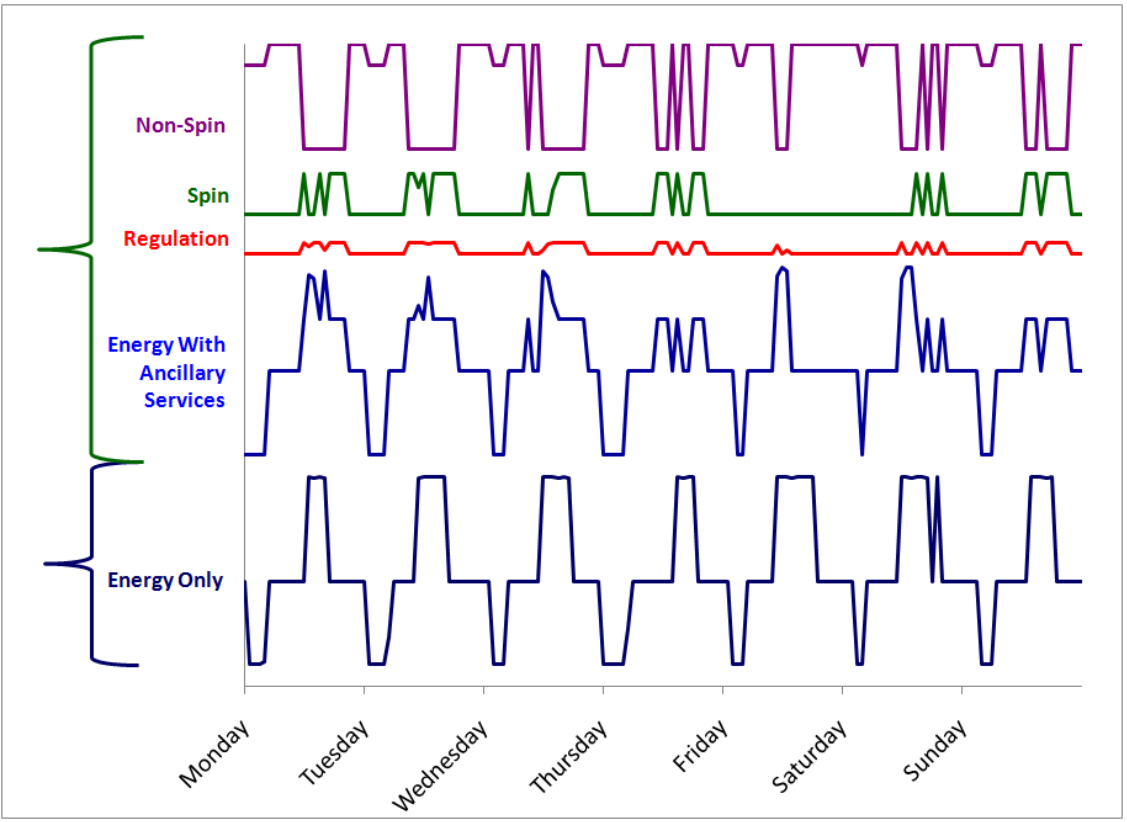
# Increases Value Through Optimized Ancillary Service (AS) Provision: *Pumped Storage Generator Example*

***(320 MW pump, 200-400 MW gen, 40 MW reg, 200 MW spin, 400 MW non)***

**CAISO market modeled for all 2010**




- *Total* profits increased 133%;
- Energy profits reduced -48%;
- Regulation profits added +41%;
- Spinning profits added +89%;
- Non-Spin profits added +50%.

**<u>*Very*</u> Flexible Plant:**

**10 MW Min Gen, 195 MW Reg, 390 MW Spin**

- *Total* profits increased 281%;
- Energy profits reduced -152%;
- Regulation profits added +156%;
- Spinning reserve profits added +258%;
- Non-Spin profits added +20%.

# Comparing Energy & Ancillary Service Results

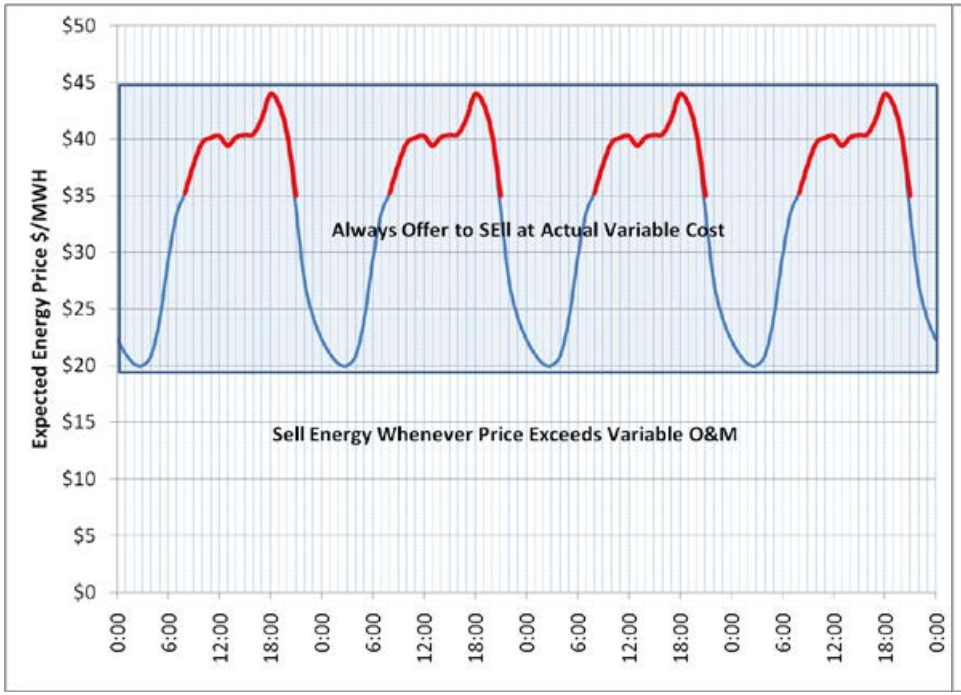
| $/KW/Yr | MISO 2009 | NYISO 2009 | NYISO 2008 |
|---|---|---|---|
| Energy | **$40.63** | $26.73 | $49.39 |
| 15% Reg | $45.42<br>111% | $44.34<br>166% | $73.01<br>148% |
| 77% Spin | $49.89<br>122% | **$60.25**<br>225% | $97.15<br>197% |

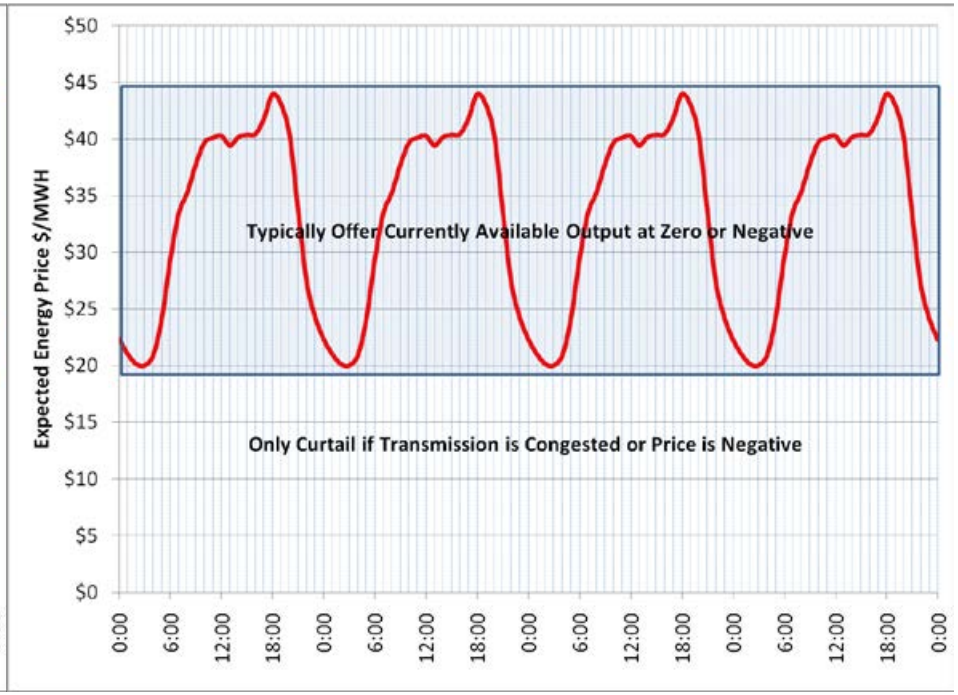
- Ancillary services during generation only;
- $5/MWH minimum spread;
- 80% efficiency;
- 16-hr storage.

# How Do You Know What to Provide Each Hour?

- Selling ancillary services requires generating at minimum load or above:
  - Must be in the energy market.
- Selling ancillary services requires being below maximum load:
  - Lost opportunity cost from energy market.
- Markets for energy and ancillary services clear each hour:
  - Prices are not known until each market clears.
- *It is essentially impossible for the generator to know what mix of energy and ancillary services to sell to maximize profits:*
  - ISOs co-optimize energy and ancillary services for conventional plants.

# Thermal and Renewable Generation



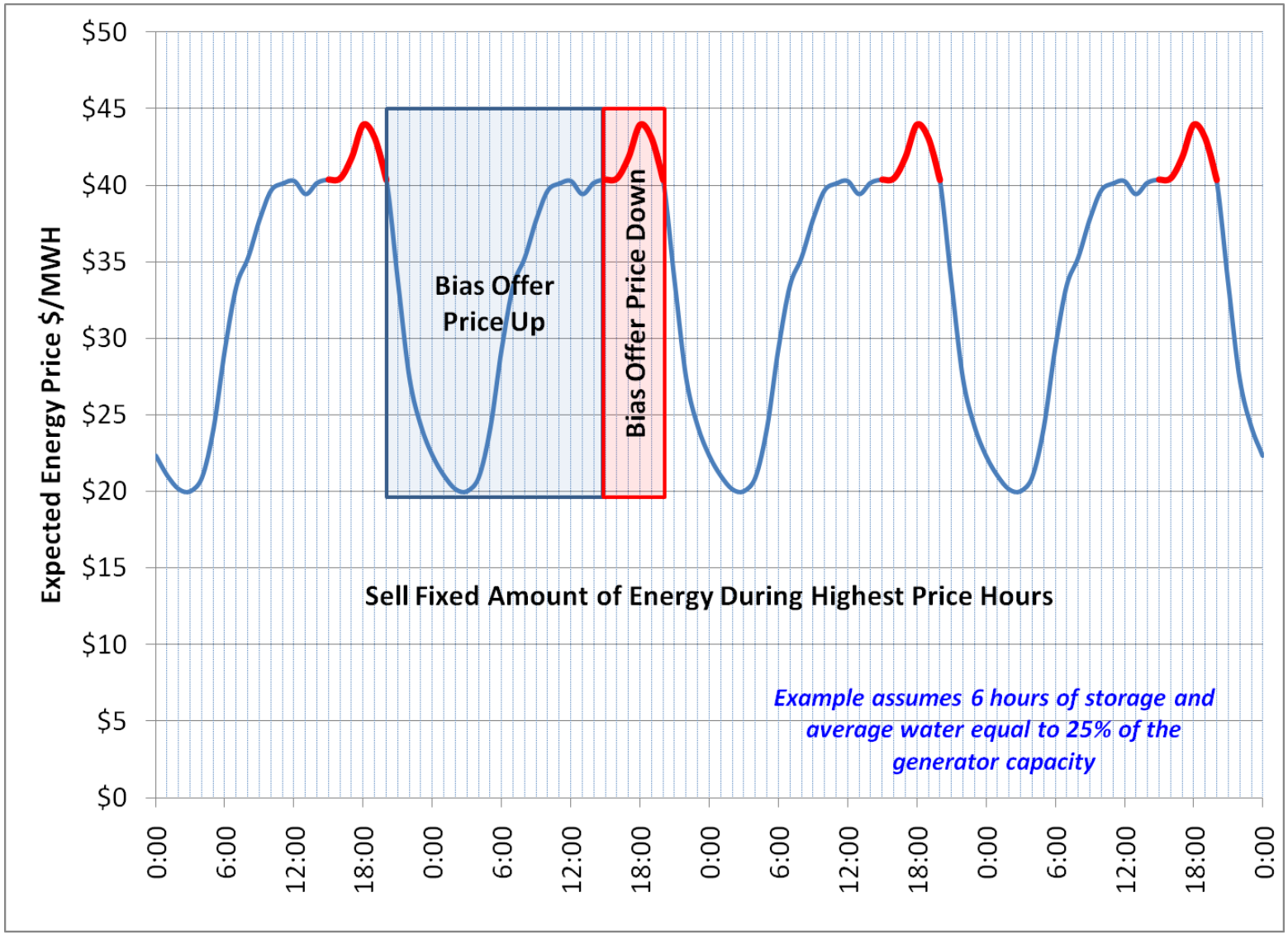




Bid variable production cost and the ISO will co-optimize and schedule output.

# Energy Limited Hydro

- Average available energy depends on water inflow;
- Storage capability depends on size of reservoir;
- Power capacity depends on size of generator;
- Variable O&M may be zero but with limited energy the plant wants to sell during the highest price hours:
  - Forecast the hours of highest price;
  - Forecast the prices themselves.
- Requires forecasting the energy market clearing prices:
  - Load forecast;
  - Availability of other generation;
  - ….

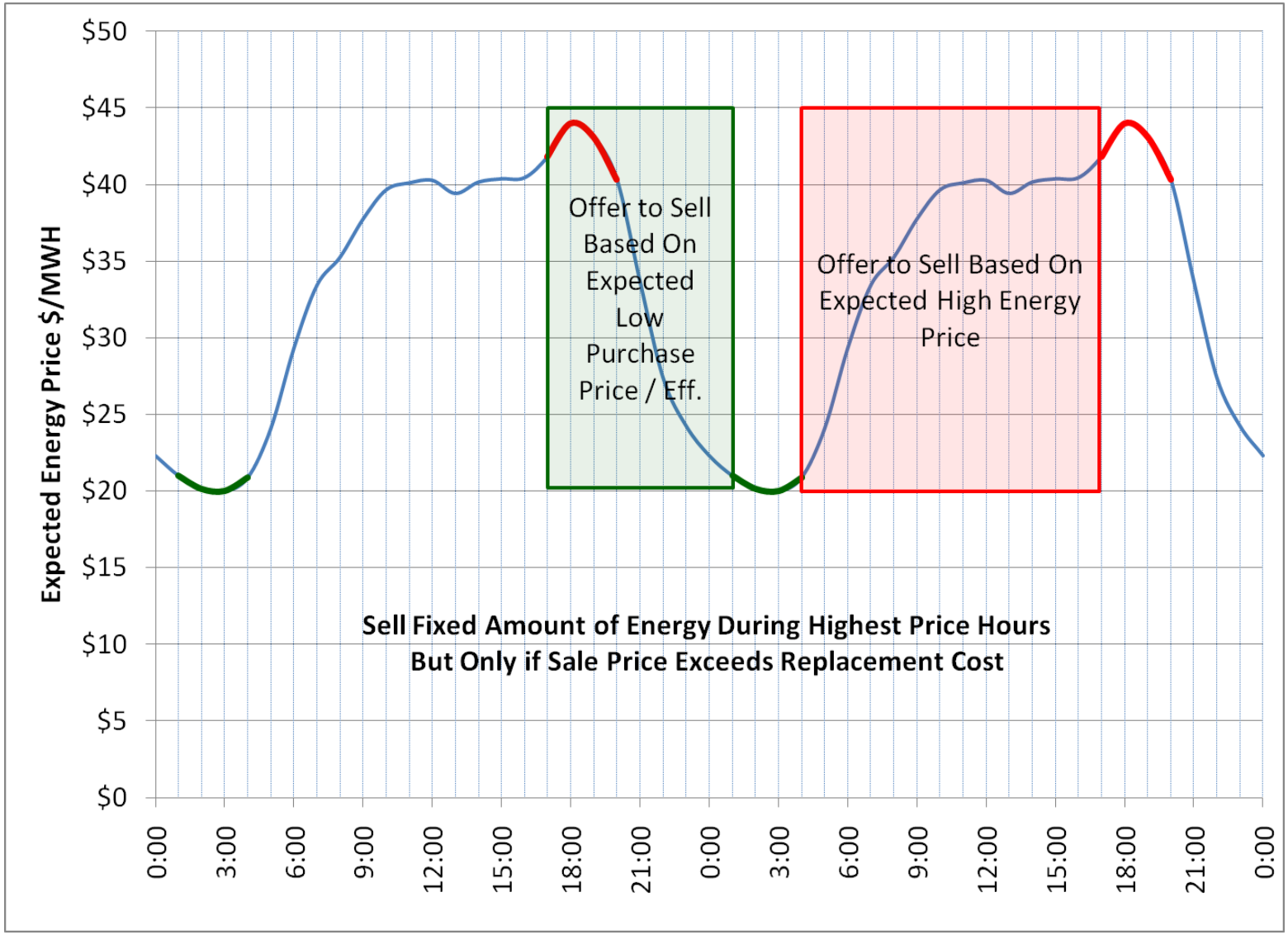
# Energy Limited Hydro



# Storage: The Most Complex

- Like thermal generation, storage has a variable O&M cost:
  - The “fuel” cost is not fixed: based on the cost of purchased energy and the round-trip storage efficiency.
- Like energy limited hydro generation, storage needs to schedule when it is best to sell its limited energy output;
- Unlike thermal and hydro, scheduling storage requires forecasting *both* the energy purchase price and the energy sale price.

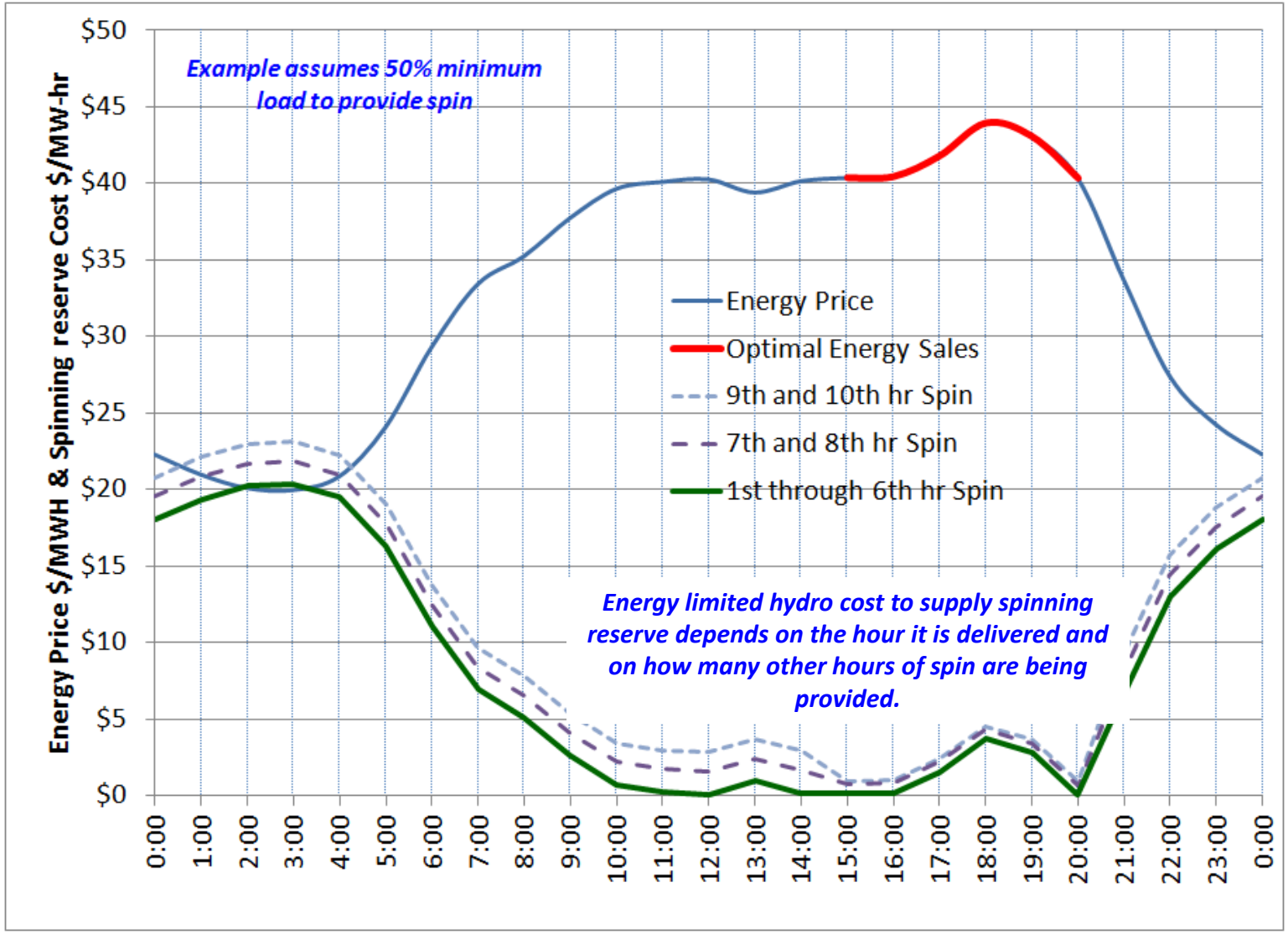
# Storage


$50
$45
$40
$35
$30
$25
$20
$15
$10
$5
$0
Expected Energy Price $/MWH
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
Offer to Sell Based On Expected Low Purchase Price / Eff.
Offer to Sell Based On Expected High Energy Price
Sell Fixed Amount of Energy During Highest Price Hours
But Only if Sale Price Exceeds Replacement Cost

# Ancillary Services Further Complicate Hydro and PS Scheduling

- The cost to supply regulation and spinning reserve is dominated by opportunity costs:
  - A thermal plant with a $35/MWh variable O&M cost selling into a $44/MWh energy market looses $9/MW-hr in profit if it backs down to provide reserves:
    - Variable O&M costs are saved, less fuel is burned, …
    - Costs are higher when selling regulation due to additional efficiency losses.
- Variable renewables have high opportunity costs and are expensive ancillary service providers:
  - $44/MW-hr in this example;
  - Wind, sun, or water must be spilled and are lost forever.
- ❖ Energy limited hydro costs depend on the next opportunity to sell:
  - Water is not spilled, so is available to sell at a later hour;
  - $4/MW-hr if the next-best energy sales opportunity is at $40/MWh.

# Spin Costs Depends on Next-Best Energy Sales Opportunity



# Co-optimizing Energy and Ancillary Services

- ISOs co-optimize energy & AS for conventional generators *each hour:*
  - Resources tell ISO their capabilities & costs;
  - Consider generator limitations: min gen, min run time, min off time, …;
  - ISO schedules energy & AS supply to simultaneously minimize system costs and maximize supplier fair-market profits:
    - Supplier does not have to guess at opportunity costs when bidding AS supply.
  - ISOs do not consider other inter-temporal constraints.
- ISOs starting to manage Energy Limited Regulation Resources (flywheels & batteries);
- *It may be appropriate for ISOs to consider managing Pumped Storage energy and AS.*

# Extending Co-optimization Over Time

- Society does not benefit from making hydro and pumped storage guess at future power prices;
- Allowing the system operator to schedule energy limited resources simply extends co-optimization over multiple market intervals:
  - Suppliers offer their capabilities and costs;
  - The ISO clears energy and ancillary service markets;
  - The ISO minimizes total costs while maximizing each supplier's profits;
  - The ISO would schedule energy limited hydro and pumped storage based on expected future conditions as well as on the current market interval.

# Storage Designed Exclusively for Ancillary Services

- *Excellent regulation resource – very fast and very accurate;*
- Bids very low every hour and is a price taker:
  - No opportunity cost;
  - Minimal direct variable cost (losses).
- Prefers regulation: highest price;
- Potential income is the hourly AS price;

❖ ***With no variable cost and a near zero bid, dedicated storage may collapse the AS market*** –
  - Regulation and spin might need to become regulated transmission services.