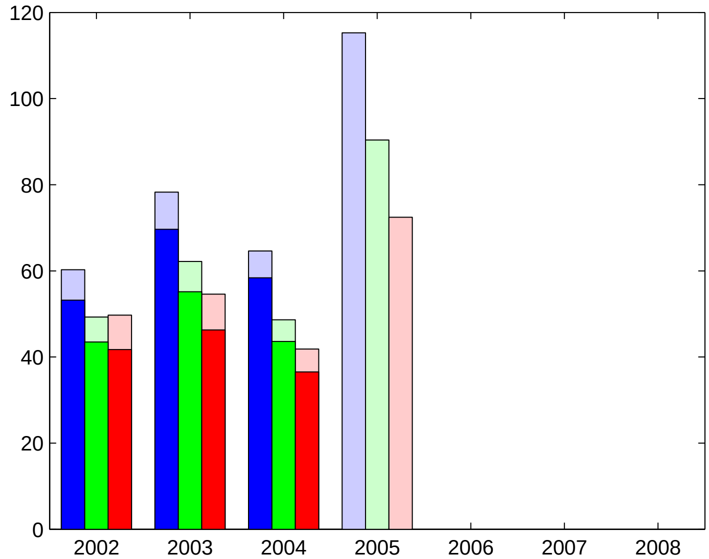
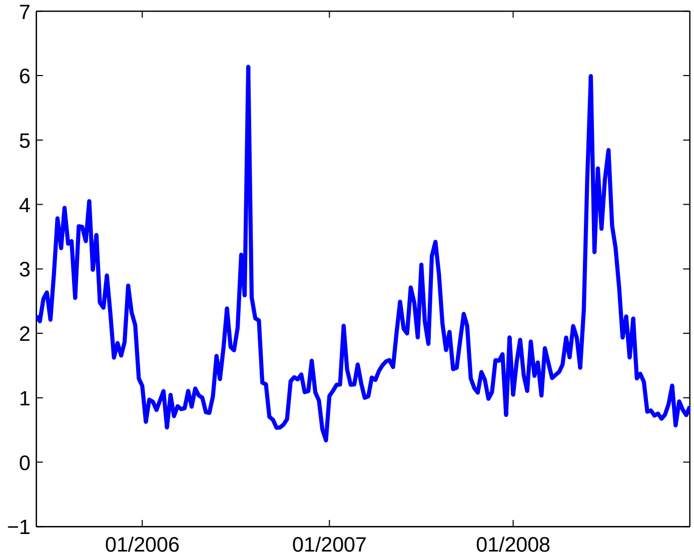
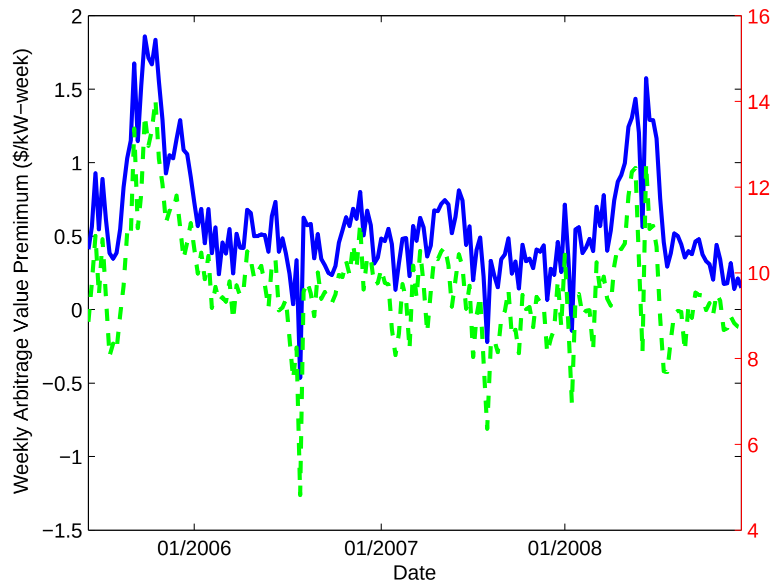
CAES, it is valuable to examine the potential differences in operation, revenues, and profitability between

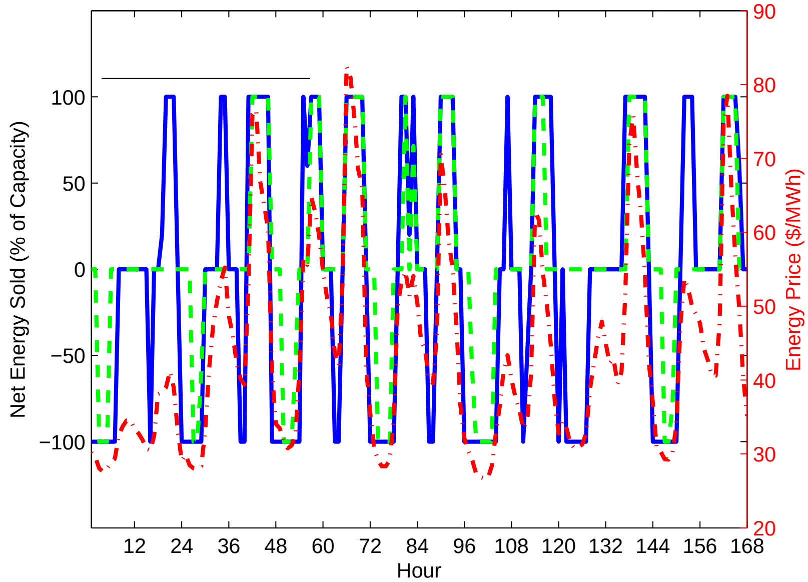
In this section we first estimate the historical annual value of arbitrage for a price-taking storage device in PJM over the seven year period 2002 through 2008. PJM refers to the PJM Interconnection, a regional transmission organization serving 51 million people in the eastern U.S. It operates an hourly day-ahead and real-time hourly energy market, as well as other capacity, transmission, and ancillary service markets. For each year the hourly operation of the storage device is optimized over successive weeks using hourly day-ahead load-weighted marginal electricity price data obtained from PJM. The optimization is conducted one week at a time to allow for inter- and intra-day arbitrage opportunities, including greater charging over weekends since hourly electricity prices tend to be lower than during weekdays, and also to reflect the fact that a storage operator would not be realistically expected to make dispatch decisions in anticipation of hourly prices many weeks in the future. In order to ensure energy stored in the device at the end of each one-week period has 'carryover value,' each optimization is done with an eight-day planning horizon to determine the dispatch of each one-week period. Otherwise, the device would be fully discharged by the end of each one-week period, which would not reflect actual device operation.[2] For pure storage the base case device is initially assumed to have perfect foresight of future hourly electricity prices over each eight-day period, an 80% round-trip e□ciency, and a variable operation and maintenance (VOM) cost of $1/MWh of generation. We also evaluate a 70%-e□cient storage device, which together with the 80% case, covers the likely range of e□ciencies of modern PHS plants, as described in ASCE (1993). This range of e□ciencies also covers most of the range of utility-scale batteries likely to be used for energy arbitrage applications, as described in EPRI (oe device. The absolute premium is $11 to 43/kW-year for an 80%-e□cient device and -$4 to 19/kW for a 70%-e□cient device.





7
6
5
4
3
2
1
0
−1
01/2006
01/2007
01/2008


Weekly Arbitrage Value Premimum ($/kW−week)
2
1.5
1
0.5
0
−0.5
−1
−1.5
16
14
12
10
8
6
4
01/2006
01/2007
01/2008
Date



Net Energy Sold (% of Capacity)
100
50
0
−50
−100
Energy Price ($/MWh)
90
80
70
60
50
40
30
20
12
24
36
48
60
72
84
96
108
120
132
144
156
168
Hour

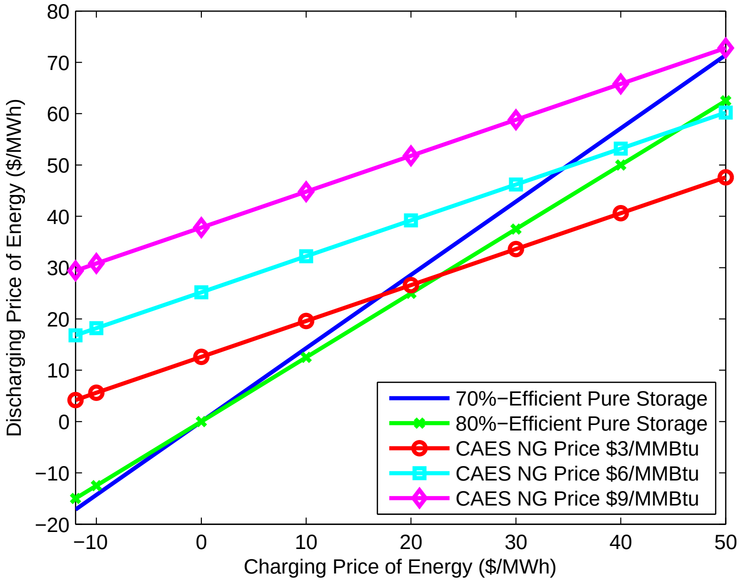


Figure 7: Minimum selling price of electricity with which pure storage and CAES would breakeven.

intraday arbitrage between the two daily peaks. This midday recharging and evening discharging behavior is also shown rTd9.061(a)-5.8.423(b)-u9.061(a)-1.22283(c)22.8662(h)111.86588445824.844582r00cmBT/R1077.68683Tf-272.4-3

Moreover, because prices from the recent past are used, any longer-term seasonal differences in prices (for instance, if peaks occur in the morning and evening due to heating and lighting during the winter) are captured using the backcasting technique. In the case of CAES, however, the greater variability of operations suggests a lower value capture using this approach.

Figure 10

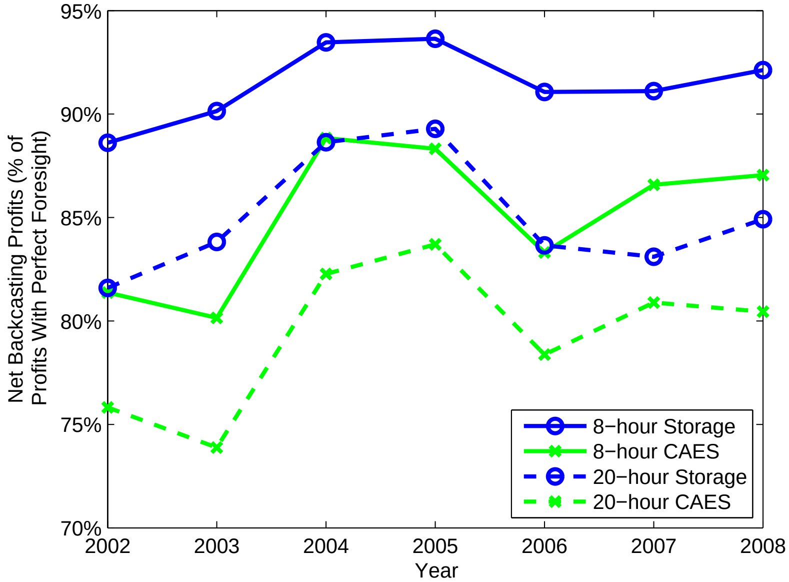


Figure 10: Net profits earned by eight- and 20-hour pure storage and CAES devices using backcasting technique and a week-long optimization horizon. Profits are given as a percentage of profits earned with perfect foresight of energy prices.

differences in both the distribution of perfect-foresight profits and the success of the backcasting technique for pure storage and CAES. The shape of the weekly perfect-foresight profit distributions are very different for pure storage and CAES due to the operational reasons identified and discussed in section 2 and also suggested by figures 8 and 9. Whereas the pure storage device earns an average weekly profit of about $1.51/kW-week with perfect foresight, the CAES device is lower averaging only $1.02/kW-week. The pure storage device also has a higher mode of about $1.15/kW-week as opposed to only $0.71/kW-week for CAES. This difference stems from the natural gas cost that the CAES device incurs. Specifically, on days with low on- and off-peak price differences the revenues of the CAES device net of natural gas costs are very small, leading to the more asymmetric distribution for CAES. In fact the weekly profits of CAES is less than $1/kW 61% of the time, as opposed to only 26% of the time for pure storage.

When profits are high the backcasting technique works well for both CAES and pure storage—typically capturing over 90% of the profits with perfect foresight. This reflects the fact that these weeks have very large differences and predictable differences between on- and off-peak electricity prices, and minor errors in forecasting operational decisions are negated by the large differences in prices. The technique performs worse, however, during weeks with smaller profits available. This is due to the fact that these weeks will not have large on- and off-peak electricity price differences, making the determination of correct operational decisions much more important. In these weeks both profits earned and operational decisions made correctly tend to be lower. However, because these weeks have lower profits available, the poor performance of the backcast is compensated by its comparatively better performance during high-value weeks.

Any practical use of storage for arbitrage purposes will have to rely on forecasting, and our backcasting technique can likely be significantly improved by using load and weather forecasts to anticipate high- and low-price periods. The preceding analysis is useful, however, in showing that the value of CAES will tend to be much more sensitive than an 80%-efficient pure storage device to making operational decisions. As a result, CAES can be expected to generally perform worse than pure storage regardless of the forecasting technique considered.[12] Thus, not only is CAES generally less valuable than pure storage (with perfect foresight of prices), but it can be more difficult to capture CAES's intrinsic value in practice without perfect knowledge of future prices.

[12] This difference is partly due to our choice of an 80%-efficient pure storage device. For a 70%-efficient storage device the average annual value capture is similar to CAES.

depend on both the discounted net revenue as well as the cost of the investment—with new CAES builds expected to have a significant cost advantage over pure storage.

It has been some time since either a PHS[13] or a CAES plant has been built in the U.S., and there are a wide range of estimates for the cost of a new PHS or CAES facility. Moreover, these estimates are site-

Table 2: Annualized return for PHS and CAES under various capital cost and revenue scenarios (%).

	PHS Revenue Scenario					
Capital Cost	Arbitrage Only			Arbitrage and Capacity		
(2008 $)	$73/kW-yr	$93/kW-yr	$113/kW-yr	$103/kW-yr	$133/kW-yr	$153/kW-yr
$2000/kW	3.7%	4.7%	5.7%			

An important question raised by this analysis is whether sto could lead to a 10% reduction in value of arbitrage. Sioshansi et al. (2009) also discussed how ownership, market and contract structure can matter greatly when considering overall societal benefits, and in particular made the point that if storage was treated as a regulated asset in a market such as PJM the societal welfare