The Viability of Grid Energy Storage and its Dependence on Natural Gas Prices

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A (Recent) History of Grid Energy Storage

New energy storage companies are established

Investment in energy storage startups/technology

Storage patents increase rapidly

Excitement builds, projections are glowing

Figures from Nanomarkets and Greentech Insights
But the storage market has not been as robust as predicted.

Grid storage projects have slowed in 2012 and 2013.

Why?
- Bad economy?
- Lack of capital?
- Emerging technology?
- Difficult policies?
Our hypothesis: Energy storage revenue is strongly dependent on natural gas price, and falling gas prices have undermined the market for storage.

Natural gas generation is a good substitute for energy storage in many applications:

- Peak shaving
- Integrating renewables
- Energy arbitrage
- Frequency regulation
We Examine Two Grid Services: Frequency Regulation and Energy Arbitrage

For each, we use historical data:

1. Natural gas prices
2. Electricity prices (including frequency regulation prices)

We then use the electricity prices in energy storage engineering-economic models to estimate:

3. Revenue that an appropriate storage device could earn providing the service
4. The breakeven capital cost of a storage device
Frequency Regulation

A grid service that requires participating generators to adjust their power output on a second-by-second basis

We model a flywheel plant providing regulation service:

1. Determine operation
2. Estimate costs
3. Calculate net revenue
Frequency regulation price is correlated with NG price.
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Monthly data for 2008 through 2013
In NY, flywheels for frequency regulation only make money when natural gas is above ~$7/mcf
With this context, the Beacon Power story makes more sense.

2008: Beacon Power gets Mass. State financing; applies for DOE loan guarantee

2009: DOE gives $43M loan guarantee for frequency regulation plant in NY

2011: Beacon Power files for bankruptcy

2013: Building 2nd plant in PA, mostly funded from ARRA (approved 2009)
“Arbitrage” of time-varying energy prices. Generally, buy and store electricity during the night to sell during peak prices during the day.

We model the operation and revenue for an 80 MWh / 20 MW storage device with 75% round-trip efficiency.
Under perfect information, storage charge/discharges frequently, taking advantage of every price fluctuation.
Without knowledge of future energy prices, storage operates less frequently and produces less revenue.

Electricity Prices

Storage operation (imperfect information)
Daily electricity price variation is correlated with natural gas price…

Henry Hub Natural Gas Price
(annual average)

Daily Variation in Electricity Price
Location: Washington, DC
(annual average)
...and energy arbitrage revenue shows a similar relationship

![Graph showing natural gas prices and storage revenue](image)

- Natural Gas Prices
- Storage Revenue
  - Location: Washington, DC
  - Perfect Information
  - Imperfect Information

Y-axis: Henry Hub NG Price ($/MMbtu, monthly average)

Y-axis: Hourly storage revenue ($, monthly average)

X-axis: Year (2003-2014)
The relationship is strong across electricity markets

West Texas
(Imperfect Information)
We also used a PJM dispatch model (PHORUM) to examine the effect of natural gas price on electricity price

- Unit commitment and economic dispatch model
  - Minimize cost of supplying electricity to meet load
  - Calculates hourly LMPs

- Models PJM as it was in 2010
  - Gas price varied from $2 - $12/MMBtu; all other fuel prices held constant
  - ~1,000 generators
  - 5-bus system

Available at https://github.com/rlueken/PHORUM
Simulated PJM electricity prices result in a trend similar to historical data.
For energy arbitrage, grid energy storage faces a tough market

Breakeven Capital Cost* under Perfect Information

* 8% interest, 15 year lifetime, 80 MWh / 20 MW device, round-trip efficiency = 75%
Conclusion: As grid storage technologies have become more mature, decreasing natural gas prices have made them uneconomic*

Favorable assessments of the potential market from 2003-2008 were reasonable at the time.

However, we are now in an era of inexpensive natural gas.

This partly explains the slow deployment of energy storage.

Energy storage companies should look seriously towards applications that do not compete with natural gas, such as off-grid and distribution.

* At least for the services and locations we
## Flywheel Properties

<table>
<thead>
<tr>
<th>Flywheel Energy Storage Parameters</th>
<th>Base-Case Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round-trip Efficiency</td>
<td>90%</td>
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<tr>
<td>Module Energy Capacity</td>
<td>0.025 MWh</td>
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<tr>
<td>Module Power Limit</td>
<td>0.1 MW</td>
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<tr>
<td>Flywheel Friction Losses</td>
<td>3% of max power (3 kW)</td>
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<tr>
<td>Module Capital Cost</td>
<td>$200K</td>
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<tr>
<td>Fixed Operating Cost</td>
<td>$5K / module - year</td>
</tr>
<tr>
<td>Length of Capital Investment</td>
<td>20 years</td>
</tr>
</tbody>
</table>
PJM grid simulation

• Unit commitment and economic dispatch model
  - Minimize cost of supplying electricity to meet load
  - Calculate hourly LMPs

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